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Golden Anniversary of FLIGHT IN CANADA

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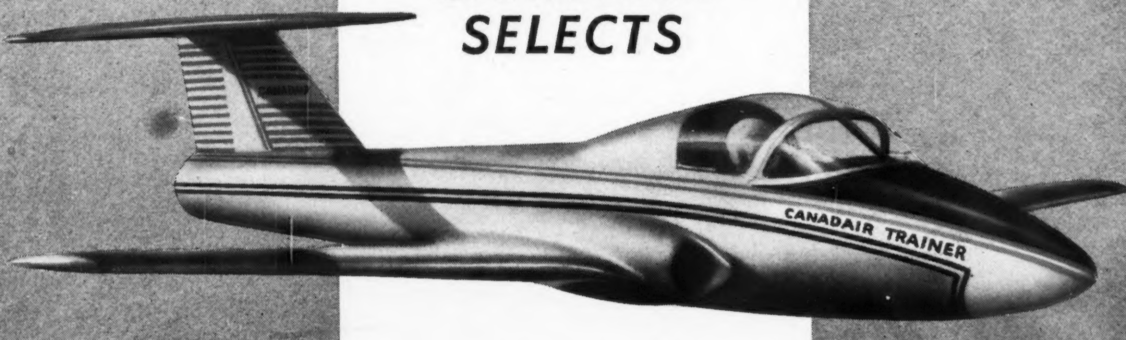
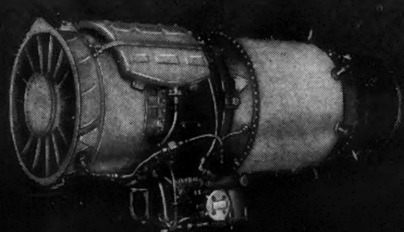

CANADAIR TRAINER



THE FIRST 50 YEARS...

The contribution of

ROLLS-ROYCE

to aviation in Canada

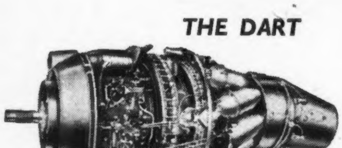
Since the early days of aviation in Canada, Rolls-Royce have contributed to many outstanding achievements. The expanding Rolls-Royce factory at Montreal is evidence of their successful co-operation with the aircraft industry of Canada and assures a high standard of service to operators of Rolls-Royce aero engines.

The Eagle, the Buzzard and the Falcon were amongst Canada's great pioneering engines. In particular the Eagle will be remembered for its part in the first direct transatlantic crossing from Newfoundland, in the first transcontinental flight and not least in the first aerial survey of Canada's undeveloped interior. The Merlin engine won fame during World War II, when over 2,000 Merlin-powered aircraft, mainly Hurricanes, Mosquitoes and Lancasters, were built in Canada. Many returned after the war, Hurricanes for training and operational purposes, Lancasters for aerial survey work and as part of the Royal Canadian Air Force Search and Rescue organisation: Merlins also power the Canadair North Star airliners, for many years the backbone of Trans-Canada Air Lines' fleet.

THE JET ERA

Canada saw its first jet fighter in October 1945 — the Gloster Meteor III powered by the Derwent — and Rolls-Royce engines assisted in the early development of Canadian-built military and civil jets. The Rolls-Royce Nene powers the T33 "Silver Star" in service with the Royal Canadian Air Force.

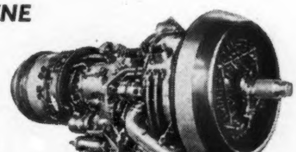
THE DART



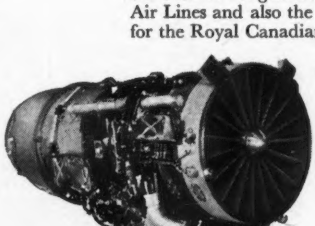
The Dart prop-jet was first introduced to Canada in February 1953 when a Vickers Viscount, after making the first prop-jet transatlantic crossing, arrived at Edmonton for winterization tests. Dart-powered Viscounts have been in service with Trans-Canada Air Lines since 1955, setting up new standards of comfort and economy on medium-distance flights. The Dart is now the most proven prop-jet in the world, with over 7,000,000 hours of scheduled airline service behind it.

THE TYNE

The Tyne prop-jet is due to enter service in 1960 at ratings of 4,985, 5,525 and 5,730 e.h.p. It is an advanced, twin-spool, high-compression engine, designed to give a very low fuel consumption. The Tyne powers the Vickers Vanguard medium-range airliner, ordered by Trans-Canada Air Lines and also the Canadair CL-44D long-range transport ordered for the Royal Canadian Air Force.



THE CONWAY



The Conway turbo jet heralds a new era in jet power. It has proved that the by-pass principle is the correct formula for all jet transport and for certain military applications. The Conway has been granted a full certificate of airworthiness by the British Air Registration Board at a minimum rating of 18,000 lb. thrust. Trans-Canada Air Lines have chosen the Conway to power their DC-8s.

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CANADIAN AERONAUTICAL INSTITUTE

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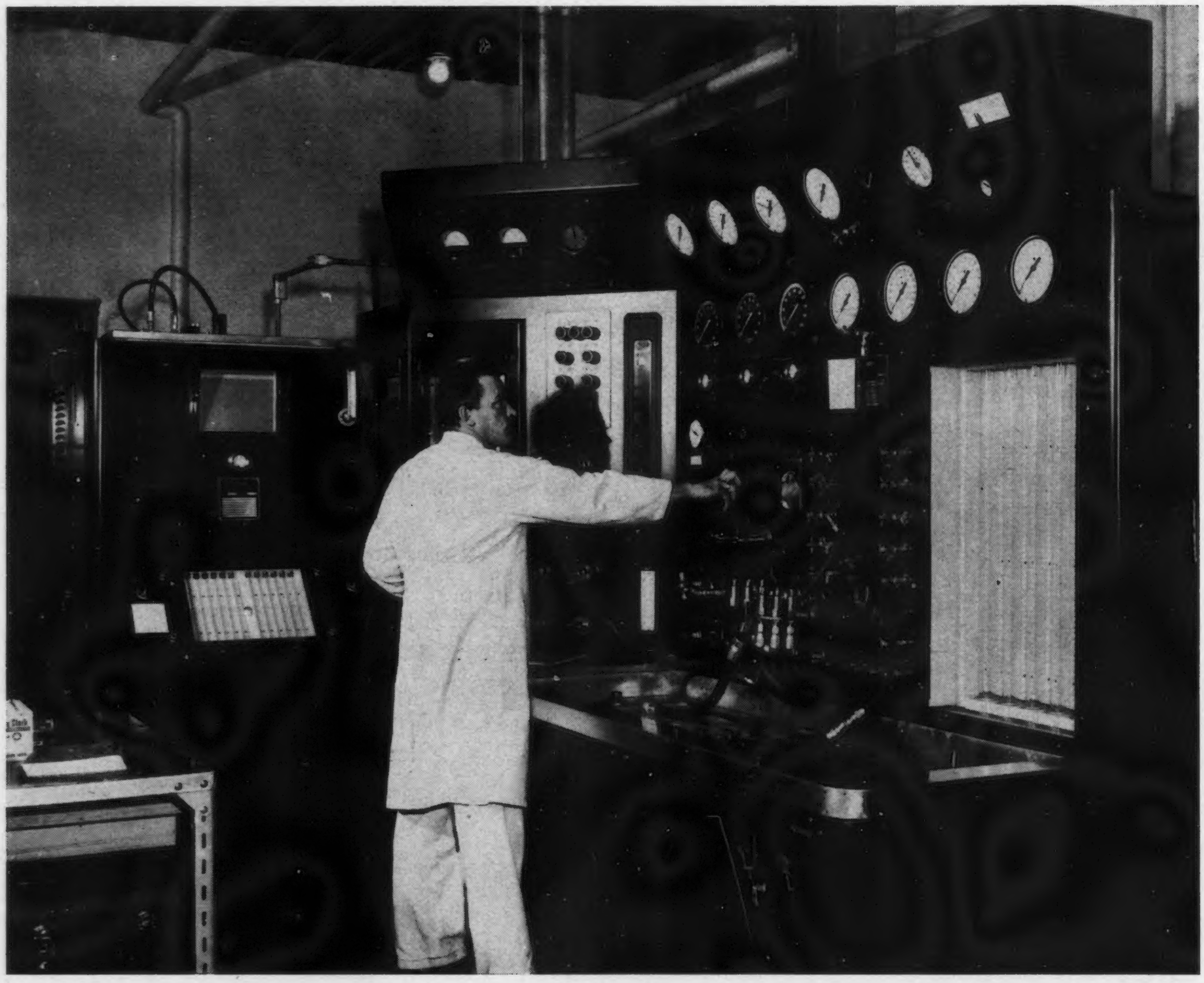
COMPONENT TEST STAND



Turbine Fuel Systems Test Stand designed by the Engineering Department of Standard Aero Engine Limited

EDITORIAL

MASTERY OF THE AIR FIRST

In October, 1957, with the successful launching of the first earth satellite, the subject of space flight became respectable. Up until that time many of the enthusiasts were subjected to criticism and ridicule. Their patience and foresight are finally being rewarded and extensive space research programmes are under way in the larger countries of the world. No doubt this is a good thing.

The subject of space flight is now a glamorous one and it receives a great deal of publicity in the popular and technical press. We also see it pointed out that some types of manned aircraft appear to be on the way out, to be replaced by appropriate kinds of missiles. Programmes for space flight research are being considered even in the smaller countries, such as Canada. Sooner or later the layman will probably come to the conclusion that the whole field of atmospheric flight is becoming obsolescent.

At the risk of being classed as a reactionary (or possibly as an aerodynamicist who senses that his vocation is evaporating), I would like to suggest that we should not be in a hurry to join the race toward outer space, at least until there is a good reason for doing so. The fact that a few of the large nations are engaged in extensive space research is hardly a good enough reason for us to try to do the same sort of thing, even on a much reduced scale. There would seem to be neither military nor economic reasons for attempting to keep up with the leaders in this field.

Fundamental research in some areas related to space flight may be of considerable interest in itself, and is probably not very expensive. If so, the fact that it is interesting may be reason enough for doing it. But substantial contributions to space technology would cost a great effort and large sums of money. Such expenditures would hardly seem to be justified at a time when there are a great many problems remaining to be solved in other fields.

In particular, the field of atmospheric flight is far from stagnant; there are many challenging problems requiring both research and development effort. It can reasonably be assumed that aircraft flight speeds will increase steadily during the next few decades until they approach satellite velocity. In the commercial field increased speeds, in order to be useful, should eventually be accompanied by some solution to the airport problem. Future growth of short-range air transport demands a solution to the same problem, since it already requires a longer time to travel from city centres to airports than to fly between airports which are about 200 miles apart or less. Difficult operational problems in the undeveloped areas, such as the Canadian north, and in a number of military operations will require continuing effort. It is possible that some of these problems may be solved by the development of more advanced types of vertical or short takeoff aircraft. Moreover there is still much to be done in the development of all-weather capability.

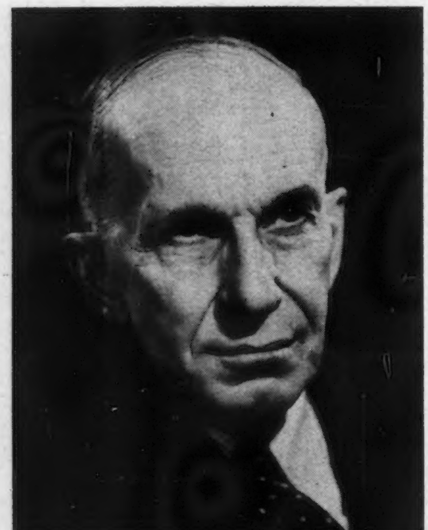
At any rate, it seems that there is plenty of work still to be done in the field of atmospheric flight. It is to be hoped that fascination with the problems of space flight will not deter us from essential progress in this and other fields.

R. J. Templin,
Section Head, Aerodynamics Section,
National Aeronautical Establishment

ADDRESS BY HIS EXCELLENCY THE RIGHT HONOURABLE VINCENT MASSEY, C.H., GOVERNOR-GENERAL OF CANADA

at the Golden Anniversary of Flight Dinner

23rd February, 1959



Gaby

His Excellency
The Right Honourable Vincent Massey, C.H.
Governor-General of Canada

I AM frequently present on occasions when I find myself an ignorant layman among experts. I am in this position now. My knowledge of aeronautics is, to employ an understatement, extremely limited. But this is an anniversary and believe me, gentlemen, I am an expert on the subject of anniversaries – I thrive on them. But to be serious, I am very happy to participate in this commemoration of an outstanding event in our national history.

People who do not know anything about aeronautics today are in a dwindling minority. The term has almost become a household word. Television and radio have made us familiar with a vast array of missiles and rockets; a great assortment of manned and unmanned aircraft. Our youngest offspring wear space suits, assemble toy aircraft and play with rockets – sometimes powerful enough to dismember them. This has all happened in a very short time. People today, of course, think nothing of boarding a jet aircraft to fly thousands of miles in a few hours. Yet, tonight, the first British subject ever to fly a heavier-than-air machine in the British Commonwealth is with us here, as we celebrate his great exploit. I was very glad indeed when I heard that there was to be a suitable commemoration of the flight of the Silver Dart which took place on this very date fifty years ago. For, as everyone here knows so well – and everyone in Canada should know – on the 23rd February, 1909, Mr. McCurdy flew his aircraft from the ice of Baddeck Bay. A year before, another Canadian, F. W. Baldwin, flew the Red Wing on a lake near Hammondsport in the United States, and so our country, thanks to these courageous men – followed closely by many others – proudly entered a new era in transportation. My pleasure in being here tonight is heightened by a personal factor. It was my privilege to know John McCurdy and "Casey" Baldwin as fellow students in the University of Toronto, even before they made their great contribution to aviation. I was interested to see in an account of Lord Grey's term of office as Governor-General that he paid a visit to Baddeck in 1909, not long after the flight of the Silver Dart, and had a talk with Dr. Alexander Graham Bell, Mr. McCurdy and Mr. Baldwin, who were closely associated with him in his researches. At this time Lord Grey drew the work of these two young men to the attention of the British Government with the comment, and I quote his words, that "McCurdy is a young Canadian whose services should be retained for the Empire . . ."

We are celebrating this evening, gentlemen, a Canadian event. I am one of those people who feel that we are inclined in this country of ours to play down our own achievements. We do not want to be boastful or smug, but things have happened and are happening of which we can be honestly proud and, if so, why should we not honour these events and pay tribute to the men who made them possible? Understatement is a virtue up to a point, but carried too far it is not helpful to the

morale of a community. We shouldn't sound our trumpets too stridently; but they should not stay silent.

The aircraft came to Canada as a godsend. It probably has meant more to us than it has to any other country. I think it is true to say that nowhere else did pioneer flying play such a part in national development – I am not thinking now of communications only and the opening up of inaccessible country, but of economic exploitation. As everyone knows, the greatest patron of the pioneer pilots in our north was the mining industry, which depended on them for the transportation of unbelievable loads of equipment.

Comme dans beaucoup d'entreprises nationales des canadiens des deux langues ont trouvé dans l'aviation un champ d'action commun. Dans un petit livre qui raconte les exploits de Roméo Vachon, trophée McKee mil neuf cent trente sept, il est dit:

"L'Histoire dire que des Canadiens français furent les pionniers du service aéro-postal dans l'est du Canada et dans cette partie lointaine et difficile de la province de Québec, le Labrador canadien, et la Côte Nord."

After the excitement of the early flights, like young birds who have enjoyed the thrill of first using their wings, our pioneer pilots turned themselves quickly to useful tasks. As in other countries, both civil and military aviation in Canada were developed side by side and interwoven, because many of our early pilots and aeronautical engineers lent their courage and their energy to both. Mr. McCurdy is a case in point. In the early years of the first World War, as most of you know well, he was busy training recruits for the Royal Flying Corps and the Royal Naval Air Service in a flying school at Toronto Island and Long Branch. The fact that all the candidates were required to secure their pilot's certificates at their own expense speaks highly of the men who volunteered to fly the fragile machines of those days. In this first school, and others which opened afterwards, I think we can detect the early quickening pulse of what was to become the Royal Canadian Air Force. Those who, at the end of the first War, computed Canada's contribution to the Royal Air Force as being approximately 22,000 airmen, could predict that on whatever day the RCAF would be officially born (it turned out to be the 1st April, 1924 – 35 years ago this year) a very promising child would be delivered. His health and vigour had been assured by such worthy forefathers as Ince, Bell-Irving, Leckie, Collishaw, Barker, McLeod, Bishop and the many others who, in those days, to the danger of flying added the menace of gun fire.

The following quotation, found in the log book of the RCAF, carries an eloquent passage describing the exploits of Captain W. A. Bishop of No. 60 Squadron of the Royal Flying Corps. It is a very familiar story, but it cannot be told too often, and it certainly should take its place on an evening like this:

"While making a lone sortie (so the story runs) in his Nieuport Scout at dawn on June 2, 1917, he (Captain Bishop) attacked a German airfield near Cambrai. As the German aeroplanes took off, he engaged them in succession and destroyed three before his ammunition was exhausted. He then flew home with his own aircraft damaged by machine gun fire from the ground. For this exploit, Captain Bishop was awarded the Victoria Cross. He had previously won the DSO and MC. By the end of August, 1917, Bishop had 47 enemy aircraft to his credit. In the spring of 1918 he won 25 more victories in 24 days, including five on the 19th June, and was awarded the DFC."

So much for Billy Bishop and his legendary career as an airman. Thus did he and many others born in this country serve the cause of the Allies in the sky.

In the years that followed the armistice, military Canadian aviation was not left idle. Another quick look at the RCAF log book reminds us of certain exploits in the early days which meant much to flying. I shall mention one. The first trans-Canada flight in 1920 was completed in just over 49 hours by relays of six aircraft, including a seaplane and two flying boats. On this occasion, Halifax and Vancouver were first linked by air at an average speed of 68 mph!

Earlier I alluded to the official birthday of the RCAF. In a country like ours which, by tradition, has never fully developed its military potential except in times when the world's freedom was at stake, perhaps one may wonder why it seemed fitting to create an Air Force in 1924. I said that civil and military aviation in Canada had been developed along parallel lines. As if to disprove Euclid's assertion that two parallel lines never meet, the military Air Force of the 1920's entered the field of civil aviation. Here is one example. In two years, Service aircraft piloted by members of the RCAF photographed more than 40,000 square miles of territory in five of our provinces. This operation was later described as the greatest of the kind ever undertaken.

Civil aviation, I need hardly say to this audience – or any other in Canada – has produced a company of great pilots in their own right. Here I am thinking particularly of those men who have worked and thriven in our northern Canadian skies. They are known to us by a phrase which expresses a sense of admiration and gratitude – the "bush pilots". Other lands have had men like them, but I think that we in Canada can take pride in the fact that our pioneer pilots have played a role of especial importance, and have faced unheard of problems and hazards. Theirs was a more than difficult job – it was a nearly impossible one. Those who managed to survive the early years – happily most of them did – will never cease to amaze us by what they accomplished. They had few instruments, most of them unreliable. The fuel gauge never worked properly and a pilot had to measure his gasoline consumption by his watch! The quality of fuel found en route in a cache could be ascertained, not by any precise information painted on the drum, but by dipping one's finger into the fluid and using the sense of smell. After the fuel had been checked it would then be filtered through the pilot's felt hat! The radio, of course, was unknown. The infant compass of those days displayed childish moods when confronted with the iron content of the equipment which might be concealed in the crates carried as a load, and allowance had to be made for them. It was even more erratic in "bush pilot" country because of the proximity of the magnetic pole. A pilot (Flight Lieut. D. A. Harding) returning to civilization in the late '20's was reported to have ignored

his compass completely and followed a flock of migratory geese which were heading south. He found them much more reliable than his bewildered compass. The existing maps told the pilots little more about our north than Cabot and Cartier learned from the charts which they brought to Canada centuries before. The maps our early fliers used had generally been drawn by trappers and coureurs de bois from memory! If we consider the comforts of life — something which those hardy pioneers seldom did — we will realize that their cockpits, whether they were open or even covered, provided but little heat.

Two names come to our minds when we think of cold flying conditions — those of "Wop" May and Vic Horner. In early January, 1929, they flew from Edmonton to Fort Vermilion, a distance of over 500 miles, to bring much needed antitoxin for the settlers of Little Red River who were stricken with diphtheria. In his fascinating book called "Canada's Flying Heritage", Frank Ellis has this to say about their flight of mercy:

> "Wop May and Vic Horner were partners and owned a small Avro Avion which had an engine of only 75 horsepower and an open cockpit. To attempt a winter flight in such a craft, particularly as they had no skis for winter landings, required courage."

I think we will agree, gentlemen, that this description coming from a man who has flown the north a great deal himself, is no overstatement. Not long ago I had the interesting experience of chatting with a few old timers who were in the north in the '20's. I have found that pilots as a rule — and bush pilots in particular — are always reticent about their personal experiences. The reason why it is so may have been given by one of the Wright Brothers when he said "the parrot is the most loquacious bird and also the poorest flier"! But however strong the tendency to understatement, illuminating stories do emerge from the legends of the pioneers. I like the story of a former bush pilot — I had the pleasure of meeting him the other day— who was on a flight east of Hudson Bay with a passenger who was a Bishop. The weather was appalling — the ceiling could not have been much lower; he was flying about fifty feet above the ground, and the visibility was equally bad — in fact he was not very far removed from what is meant by the ominous phrase "weather zero, zero" — but there was nothing for it but to go on. He wondered how his passenger was faring and how alarmed he must be. He looked round and found the Bishop obviously enjoying every minute of the flight, looking out of the windows and saying in tones of enthusiastic interest that he was able to identify places where he had camped on canoe trips some years before — and wishing it were possible to get a rather closer view! Where ignorance is bliss . . .!

The old cliché says that necessity is the mother of invention. The truism has been illustrated time and again by our early fliers — never more graphically perhaps than by a mechanic named William Hill, and a cabinet maker called Walter Johnson. A propeller blade had been broken in a crash landing, on the Mackenzie River in winter weather. These two men carved out of an oak sleigh board what would now be called a "do-it-yourself" propeller. Here I quote from an account of the achievement:

> "the one unbroken propeller blade was used as a model. Numerous templates were cut to shape for use in forming new propellers, the plans were laid out, and with babiche glue made at the post from the hide and hoofs of a moose, the laminations were glued together and clamped tightly in place. Everyone at the post assisted to the best of his ability, but the work which occupied two weary weeks was done mostly by Hill and Johnson."

And later in the narrative:

> "the new propeller cut the northern air with a smooth, steady rhythm and took them in a straight 500 mile non-stop flight to Peace River in six hours."

What I have just said about Hill and Johnson speaks highly of Canadian resourcefulness when it is confronted by a predicament. But we can take equal pride in the ingenuity of our engineers who successfully applied their intelligence to the solution of many aeronautical problems encountered in the days of early flying.

The reproduction of the Silver Dart, for which we can thank LAC Lionel McCaffrey of the RCAF, has enabled us to compare this aeronautical ghost of our past with the sleek aircraft of today. A flying machine whose bamboo struts were held together by piano wire, and equipped with the crudest controls, has evolved into modern aircraft whose structure can withstand twenty-mile-a-minute flights; vertical take off aircraft that perform conventionally once airborne; helicopters and aircraft that land on aircraft carriers. Some are now able to land in a "pea-soup" fog flown by the brainchild of aviation engineers — the autopilot — faithfully answering to information received from the ground.

Modern man, who takes progress in his stride and is not easily moved to profess enthusiasm, cannot but admire the genius of those who, over the last fifty years, have transformed what at first were oversize kites into the reliable and speedy craft of today.

W. R. Turnbull is a Canadian example of the type of man I have in mind. In 1902 he constructed Canada's first wind tunnel at Rothesay, New Brunswick. From 1908 to 1911 he experimented with "aerial propellers" and his findings led him to invent the first controllable pitch propeller, whose modified revisions are now commonly used.

There is a fine passage in a book by the French airman Saint-Exupéry, "Wind, Sand and Stars", with which you may be familiar. I read it in translation. It is too fine to be abridged:

> "and now", he says, "having spoken of the men born of the pilot's craft, I shall say something about the tool with which they worked — the aeroplane. Have you looked at a modern aeroplane? Have you followed from year to year the evolution of its lines? Have you ever thought, not only about the aeroplane but about whatever man builds, that all of man's industrial efforts, all his computations and calculations, all the nights spent over working draughts and blueprints invariably culminate in the production of a thing whose sole and guilding principle is the ultimate principle of simplicity?
>
> "It results from these, that perfection of invention touches hands with absence of invention, as if that line which the human eye will follow with effortless

delight were a line that had not been invented but simply discovered; had, in the beginning, been hidden by nature and in the end been found by the engineer.

"In this spirit do engineers, physicists concerned with aerodynamics, and the swarm of preoccupied draughtsmen tackle their work. In appearance, but only in appearance, they seem to be polishing surfaces and refining away angles, easing this joint or stabilising that wing, rendering these parts invisible, so that, in the end there is no longer a wing hooked to a frame-work, but a form, flawless in its perfection, completely disengaged from its matrix – a sort of spontaneous whole, its parts mysteriously fused together and resembling in their unity a poem."

Saint-Exupéry, as a great airman, knew intimately the relation between pilot and aircraft, the marriage between man and his machine. We celebrate such a union tonight – a union of fifty years ago.

ANNUAL GENERAL MEETING

KELTIC LODGE
INGONISH, N.S.

15th, 16th and 17th June, 1959

15th June . . .	Morning–9.00 a.m. to 10.30 a.m. .	Business Meeting
	Morning–10.45 a.m. to 12.00 noon .	Test Pilots Section / Propulsion Section / Astronautics Section } Concurrently
	Afternoon–2.30 p.m. to 5.00 p.m. .	Honours and Awards and the W. Rupert Turnbull Lecture
	Evening–7.00 p.m.	Dinner

The Principal Speaker at the dinner will be
PROFESSOR T. R. LOUDON

16th June . . .	Morning–9.00 a.m. to 12.00 noon .	Flying–Past, Present and Future
	Afternoon–2.00 p.m. to 5.00 p.m. .	Hydrodynamics

17th June . . . A visit to Baddeck, to unveil a Monument to the Aerial Experiment Association and the Silver Dart in the grounds of the Alexander Graham Bell Museum.

DESIGN AND APPLICATIONS OF MACH 4 TURBINE ENGINES†

by M. A. Zipkin* and R. E. Neitzel**

General Electric Company

SUMMARY

The performance of turbine engines designed to power self accelerating Mach 4 vehicles is considered in this paper. Engine performance requirements are related to the mission with particular attention paid to the acceleration of the vehicle. A straight Mach 4 turbojet engine is described and the factors involved in the selection of the cycle are presented. A turbojet-ramjet engine (dual cycle) which would be based on an existing Mach 3 turbojet is also described and then compared with the straight turbojet. Applications of Mach 4 turbine engines to manned aircraft and missiles are examined and the features which make the turbine engine powered vehicles attractive are discussed. Some generalized mission performance is shown which indicates a high potential for Mach 4 turbine engines.

INTRODUCTION

THE turbojet engine is the accepted means of propulsion for vehicles in the low supersonic speed regime with several types of aircraft and missiles in the Mach 2 category now operational. Turbojet engines designed to power vehicles in the Mach 3 category are now in development and will power the next generation of airbreathing vehicles. Engines for Mach 4 flight are a logical next step. This paper examines the requirements of engines to power vehicles for Mach 4 missions and in particular the acceleration of the vehicle to its Mach 4 cruise condition is explored.

Several approaches to the Mach 4 turbine engine are possible. In this paper, the term "turbine engine" is meant to apply to airbreathing engines which include turbomachinery as an integral part of the engine. The first approach is a straight turbojet engine designed for acceleration to and cruise at Mach 4. The factors involved in the selection of the cycle are described and the characteristics of a typical engine shown. Although the emphasis in the paper is on the performance aspects of high Mach engines, the problem of structural design for low weight and the problems of design of auxiliary equipment, such as the fuel and control systems in the Mach 4 environment, should not be overlooked. Indeed, recent advances in these areas now indicate that the Mach 4 turbojet should be a straightforward development in the pattern of the Mach 2 and Mach 3 turbojet engines.

The second approach for Mach 4 flight is the combined turbojet-ramjet or dual cycle. Here a gas generator developed for flight at less than Mach 4 would be used up to its maximum flight speed. It would then be bypassed and a common afterburner-jet nozzle system used as a ramjet engine at the higher flight speeds. The advantages and disadvantages of this approach compared with the straight turbojet are described. Other approaches to the Mach 4 turbine engine, such as the turbofan and the turborocket, are possible, but will not be discussed in this paper.

Turbine engine powered vehicles, whether manned or unmanned, have characteristics which make them competitive for a variety of missions. First, the turbine engine powers the vehicle over its entire mission, providing thrust for takeoff, acceleration and maneuver, and fuel economy at cruise. Since it has good efficiency over the entire flight speed range, the gross weight of the system is smaller for most missions than for those using competitive powerplants. Moreover, most missions can be effectively performed using conventional jet fuel although engines can be adapted to use other fuels for specialized missions. The features which make such vehicles attractive include the fact that the vehicle is powered over the entire flight and uses aerodynamic surfaces for control. Thus the flight can be closely controlled or guided, leading to high accuracy to the target. In addition, evasive action can be taken and alternate missions performed, both of which will decrease vulnerability. Finally, the turbine engine takes advantage of the large body of experience both in industry and the military in the development and operational use of such engines.

RELATION BETWEEN MISSION AND ENGINE PERFORMANCE

The turbine engine must provide adequate thrust for acceleration of a vehicle to Mach 4 and subsequently good fuel economy for cruise at this flight speed. The acceleration capabilities are determined primarily by the characteristics of the turbomachinery. Cruise efficiency on the other hand is only slighty affected by the turbomachinery since the engine performs much like a ramjet. In order to illustrate the performance requirements of the engine, the results of a simplified but representative study will be presented. Cruise performance will be held constant and the acceleration region examined.

In Figure 1 is shown a possible acceleration flight path of a Mach 4 vehicle. It can be shown that the acceleration is most efficient in terms of fuel required when the ratio of thrust to drag is highest. This occurs

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 7th October, 1958.

*Manager, Advanced Propulsion Systems.

**Critical Problems Engineer, Flight Propulsion Lab. Dept.

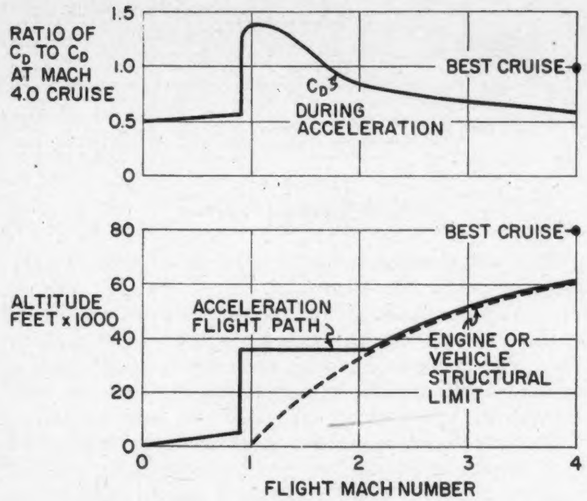


Figure 1

Acceleration of a Mach 4 vehicle

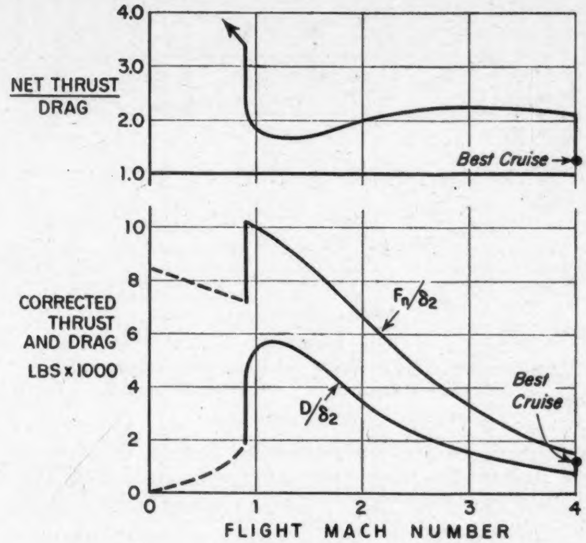


Figure 2

Comparison of engine thrust and vehicle drag

along the engine or airframe limit at the higher Mach numbers. At the lower Mach numbers where the engine limit is below the tropopause, the effect of altitude on ambient temperature is such that the thrust/drag ratio is not a strong function of altitude. The flight path shown includes a constant Mach number climb at 0.9 Mach number and a constant altitude acceleration at 36,000 ft although an accelerated climb at lower altitudes is also a reasonable flight path. The initial best cruise point is shown at Mach 4 at 80,000 ft with the remainder of the cruise assumed to follow a Brequet path. Also shown in Figure 1 is a sample drag coefficient curve along the prescribed flight path. It is realized that considerable variation can occur with different vehicle designs, but it is felt that the curve shown will satisfactorily illustrate the engine requirements.

Shown in the lower part of Figure 2 is the variation of corrected net thrust of a typical turbojet engine described later in the report. The engine performance shown in this paper will be that of gas generator plus nozzle with inlet drag and other illustration losses charged to the vehicle. Also shown in Figure 2 is the airframe drag replotted from Figure 1. Here the engine and vehicle have been sized for efficient acceleration of the vehicle. In the upper part of Figure 2 the ratio of thrust to drag is plotted. It is seen that the lowest ratio of thrust to drag tends to occur in the low supersonic speed region and it is this region which usually sizes the turbomachinery. If the engine is sized for adequate margin in this region, sufficient thrust for normal takeoff is also obtained.

At the cruise condition, a moderate amount of excess thrust is available which means that the engine can be throttled back for cruise giving slightly better fuel economy. For most missions, only a small amount of excess thrust will be needed at cruise conditions. For certain missions, such as an interceptor mission, maneuver requirements at high Mach number and altitude will require additional thrust. It is only for such an application that the high Mach condition will influence the sizing of the engine.

In order to illustrate the sizing of an engine for efficient acceleration, the fuel required to accelerate a vehicle is shown in Figure 3 as a function of an average thrust to drag ratio over the acceleration flight path. Variation of the latter parameter is equivalent to changing the size of the engine relative to the vehicle. Note that hydrocarbon fuel is used in this and other figures in this paper. An increase in the thrust decreases the acceleration fuel required, but increases the engine weight as shown for a typical case in Figure 3. If acceleration fuel and engine weight are equally important, the minimum point for the sum of these would be optimum. Since engine weight is probably more important, a somewhat lower thrust would be optimum although other factors, such as the desire for shorter takeoff distance, would push it to higher thrusts. An average thrust to drag ratio of 2 seems to be a reasonable compromise. In any event, the result is that a relatively

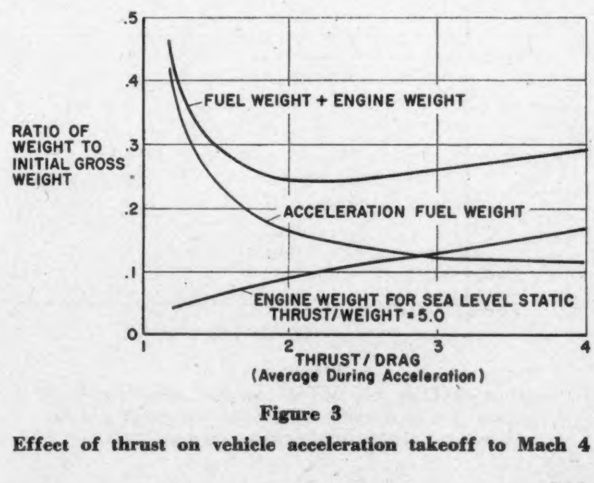


Figure 3

Effect of thrust on vehicle acceleration takeoff to Mach 4

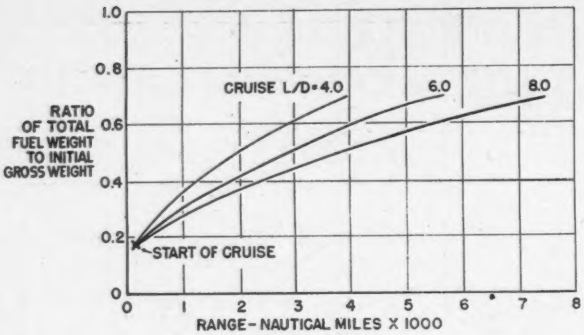


Figure 4
Fuel required to perform missions of various ranges
Mach 4 cruise Cruise sfc = 2.5

high thrust to drag ratio is needed and, on the basis of the typical thrust/drag relationship shown in Figure 2, the low supersonic speed region is limiting in this respect.

The range of the vehicle depends primarily upon the aerodynamic efficiency of the vehicle. This is illustrated in Figure 4 where the required ratio of total takeoff fuel weight is plotted as a function of range and vehicle lift/drag ratio for a representative level of Mach 4 engine performance. The acceleration phase based on an average thrust/drag ratio of 2 taken from the previous figure is included. For example a vehicle with 60% fuel at takeoff and a cruise lift/drag ratio of 6 would have a range of approximately 4,000 nautical miles. The engine performance will also affect the range of the vehicle but, as will be indicated later in the paper, the possible changes are not large. A change in cruise sfc will change the range directly for a given vehicle mass ratio. The cruise sfc tends to be more important at long ranges where the amount of cruise fuel is a large portion of vehicle weight. The level of cruise thrust is usually not a factor except to the extent it affects the cruise sfc.

To complete the story on what mission performance is possible using Mach 4 turbine engines burning hydrocarbon fuel, the ratio of payload plus fixed weight to takeoff weight is plotted in Figure 5 as a function of range and cruise lift/drag ratio. Structural

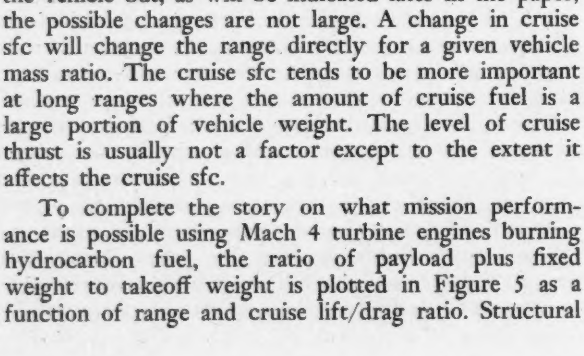


Figure 5
Payload capabilities of turbine engine powered Mach 4 vehicles. Sea level static engine thrust/weight = 5.0. Structural weight/initial gross weight = 0.25

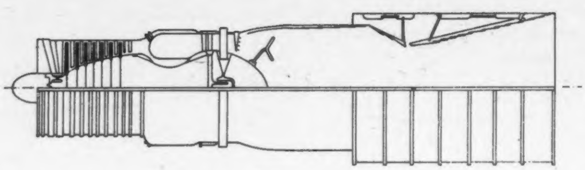


Figure 6
Mach 4 turbojet engine

weight was assumed to be 25% of initial gross weight and the engine sea level static thrust/weight ratio to be 5. As an example of the mission performance shown in this curve, a vehicle with a range of 1,500 nautical miles and a cruise lift/drag ratio of 6 would have a payload of about 33% of takeoff weight. This is a very impressive capability which would be hard to match with competitive propulsion systems. In general, some very attractive payload to gross weight ratios can be obtained for short and intermediate ranges with moderate lift/drag ratios, and for longer ranges with high lift/drag ratios.

THE MACH 4 TURBOJET

The turbojet engine is a straightforward powerplant for self accelerating high speed vehicles. A typical Mach 4 turbojet is shown in Figure 6. This is a moderately low pressure ratio reheat engine designed for the acceleration to Mach 4 and cruise at Mach 4. A conventional multistage axial compressor is used, driven by a single stage turbine of moderate inlet temperature. The engine is run at constant speed over its entire operating range, with variations in thrust obtained by varying afterburner temperature. The afterburner is of conventional construction and uses a film cooled liner, turbine discharge air being the cooling medium. The nozzle, which is a major component on a Mach 4 engine, is of the ejector or bypass type having variable primary and secondary throat areas, but fixed exit area. The type shown has low weight for the high level of performance possible when adequate secondary air is supplied at lower flight speeds. It should be noted that only the compressor of all the major components operates in an environment more severe than that of current engines.

In this paper, the selection of the cycle will be discussed with consideration given to the performance with different limitations applied to the engine design. In Figure 7 is shown the performance of the typical Mach 4 turbojet along the flight path shown in Figure 1. The significant cycle parameters of this engine are tabulated in the figure, with other parameters and losses either held constant or varied in a reasonable manner with flight speed. The engine is sized for 100 lb/sec sea level static flow for convenience. The effect of variations from this design on engine performance are shown in the next series of figures and the factors involved in the selection of the cycle are discussed.

The effect of increasing the turbine inlet temperature is shown in Figure 8. Since internal cooling is the only way in which higher turbine temperatures can be obtained without a breakthrough in materials, some representative amounts of cooling air are assumed. The result is that a moderate gain in performance can be

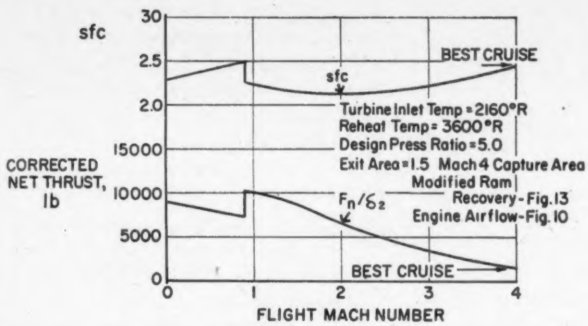


Figure 7

Performance of typical Mach 4 turbojet along flight path of Figure 1

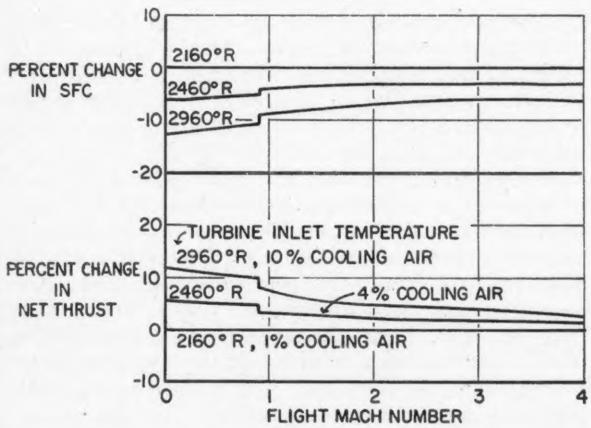


Figure 8

Effect of turbine inlet temperature on turbojet performance (relative to Figure 7), airflow schedule held constant

obtained, the amount being greatest at low flight speeds. Two factors which influence the designer to the lower temperatures are the complexity of internally cooled turbines and the increased turbine discharge temperature. The latter is especially important since turbine discharge air is used for afterburner and nozzle cooling. When this is above a certain level, conventional approaches to the afterburner design cannot be used and new approaches must be counted on. Since the Mach 4 turbojet with moderate turbine temperature has attractive performance, the authors believe that it is not necessary to go to high temperatures except perhaps for extremely long range missions where cruise sfc becomes critical.

The effect of afterburner temperature on performance is shown in Figure 9. At cruise the approach would normally be to throttle back the reheat temperature to the point where best sfc is obtained, provided the thrust is sufficient. During the acceleration, high thrust is important, but sfc is also a factor, particularly when the high thrust to drag ratios recommended in this paper are used. Higher thrusts are always desirable at takeoff, but the gain due to high reheat temperature is small and hard to obtain. For these reasons, the authors believe that state of the art reheat temperatures are satisfactory for the Mach 4 turbojet.

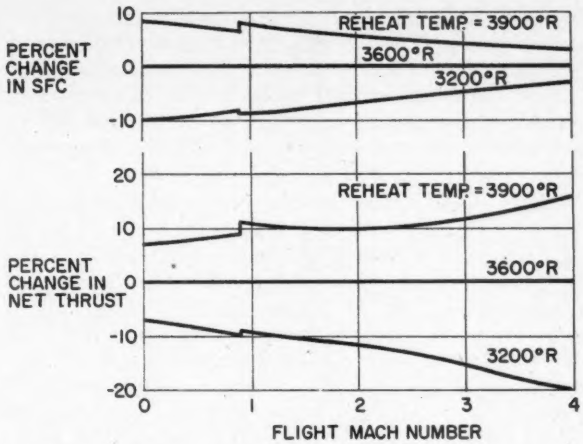


Figure 9

Effect of reheat temperature on turbojet performance (relative to Figure 7), airflow schedule held constant, constant combustion efficiency

The selection of the compressor pressure ratio involves several factors. In this paper it is assumed that the compressor is designed for a low flight speed condition. This is desirable since the turbomachinery must be sized to give the required thrust at low flight speeds. Furthermore, the engine is run at a constant rotational speed at all flight speeds which is desirable since it takes full advantage of the capabilities of the engine at each flight speed. The resulting compressor flow characteristics for fixed geometry compressors with design pressure ratios of 3.5, 5 and 7.5 are shown in Figure 10. This is not to imply that other flow characteristics cannot be obtained, but they require other approaches, such as variable speed or variable geometry, which complicate the engine design. The compressor efficiency characteristics shown in Figure 10 illustrate the rather unusual operation of the compressor in a Mach 4 turbojet. At the higher flight speeds, the compressor operates at a very low pressure ratio compared

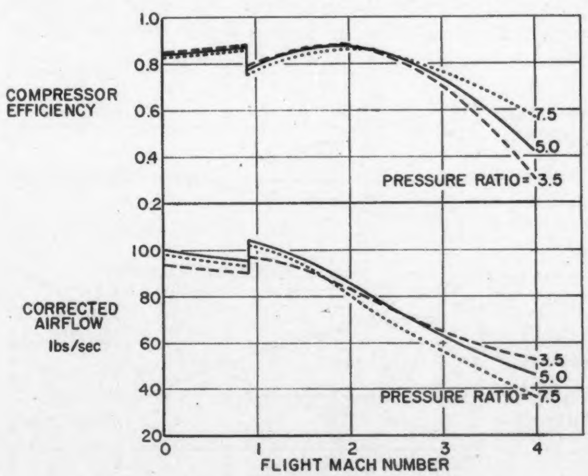


Figure 10

Effect of design pressure ratio (sea level static) on compressor performance, constant rotational speed, constant engine weight

with the peak efficiency pressure ratio at the same corrected speed. The low efficiencies shown are not as serious as they might seem since the compressor energy is low, but some loss does result. At the same time, these low compressor pressure ratios mean that there will be no compressor stall problem and that the compressor will be tolerant to inlet distortion at Mach 4.

The engine airflows shown for the different pressure ratios in Figure 10 are for equal engine weights and the engine performance will be compared on this basis. The 3.5 pressure ratio engine does not have an advantage in weight when sized for a given sea level static airflow, even though a smaller number of compressor stages are needed. The reason for this is that the turbine and afterburner must be larger due to the lower pressure level behind the turbine and in the afterburner when compared with a higher pressure ratio engine. The lower pressure ratio engine does have a higher flow capability at the high flight speeds. The jet nozzle must be sized for the Mach 4 flow and this also contributes to the weight difference.

The performance changes with design pressure ratio are shown in Figure 11. The most pronounced effect is the change in thrust variation with flight speed. In the discussion on engine requirements, the 5 pressure ratio engine was shown to have a reasonable thrust characteristic for a self accelerating cruise vehicle, with the low supersonic speed region tending to have the smallest thrust margin. It is possible that the lower pressure ratio engine would have inadequate thrust in the low supersonic speed region unless the engine were oversized, which would result in a penalty in weight. The low pressure ratio engine does give higher thrust at Mach 4 and would be better suited for an application where such thrust was needed. The higher pressure ratio engine has a thrust characteristic suited for an application requiring high thrust at low speeds. The good low speed sfc of the higher pressure ratio engines also contributes to their desirability for the acceleration phase of a mission. The difference in sfc at Mach 4 is quite small with a small advantage of the lowest design pressure ratio. The writers believe that a pressure ratio near 5 is a good compromise between the high Mach 4 thrust of a low

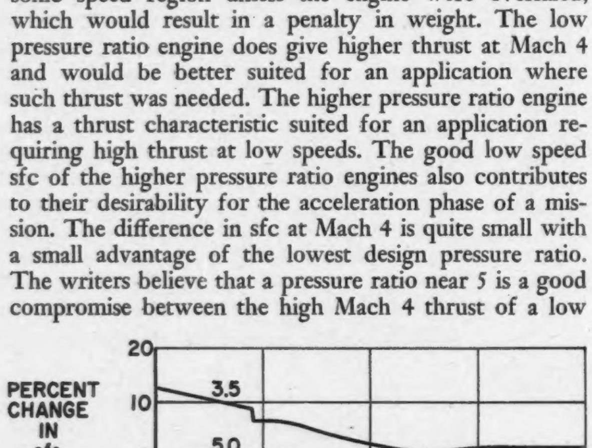


Figure 11

Effect of design pressure ratio on turbojet performance (relative to Figure 7), constant engine weight basis

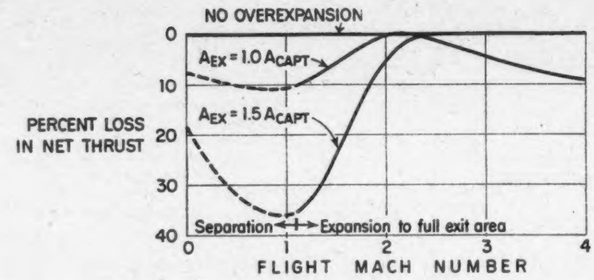


Figure 12

Effect of nozzle exit area on turbojet performance (relative to Figure 7), airflow schedule held constant

pressure ratio engine and the superior acceleration performance of a higher pressure ratio engine.

The jet nozzle has a major effect on the performance of a Mach 4 turbojet engine. This is illustrated in Figure 12 where the effect of exit area and overexpansion are shown. The performance of the base engine was computed on the basis of an exit area equal to 1.5 times the Mach 4 capture area at high flight speeds and no overexpansion losses at low flight speeds. The possible losses due to overexpansion are shown in Figure 12 with the dotted portion of the curve corresponding to separation from the internal walls of the nozzle. The losses are high in the low supersonic speed region where thrust is most critical. One way of decreasing these losses is to reduce the exit area, but this causes a loss in Mach 4 performance. This might be acceptable in an application where simplicity is more important than the associated performance losses. For most applications, however, something would have to be done to minimize the losses in the low supersonic speed region. Variable exit area is one possibility, while the method shown in this paper involves the use of high secondary flows in the low flight speed region.

The effect of inlet pressure recovery is shown in Figure 13. The base engine performance was computed for the modified ram recovery schedule shown, which

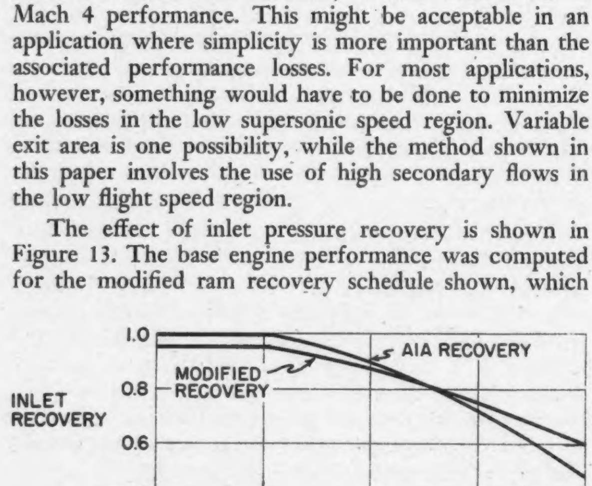


Figure 13

Effect of recovery on turbojet performance (relative to Figure 7), airflow schedule held constant

is higher than the AIA curve at Mach 4 and accounts for some loss at subsonic speeds. The primary effect on performance is a significant change in the thrust versus flight speed characteristics. This is important to the engine designer since it may change the point at which engine thrust is marginal and may also change the nozzle exit area requirements.

Another factor which will only be mentioned in this paper is that of inlet matching. The relation between the engine airflow characteristics and the inlet has considerable effect on the inlet drag losses. In particular, flow must be spilled around the inlet or bypassed around the engine in the low supersonic region. High engine flow in this region relative to the Mach 4 flow is generally desirable in order to reduce the spillage losses.

THE MACH 4 TURBOJET-RAMJET

The ramjet engine has somewhat better performance at the Mach 4 condition than does the straight turbojet engine since a significant pressure drop occurs in the turbomachinery of the turbojet. A ramjet, however, does not have self accelerating capabilities and must be used in conjunction with another means of propulsion for the boost phase of the mission. A reheat turbojet, which might be called a supercharged ramjet, has excellent performance as a boost propulsion system, and a reasonable approach to a Mach 4 powerplant is to convert such an engine to a ramjet engine at cruise conditions and thereby gain the associated performance advantages. The resulting powerplant will be termed a turbojet-ramjet in this paper. It has also been called a "dual cycle" engine.

The selection of the cycle of the turbojet-ramjet could proceed on the same basis as that described for the straight turbojet. However, there is one factor that tends to make such an exercise unnecessary. That is the fact that a gas generator originally designed for a lower flight speed capability can be used in such an application. The portion of the engine to the rear of the turbine would have to be designed and developed for the new application, but the turbomachinery which always involves a considerable development effort can be used with only the minor changes necessary to make it withstand the higher soaking temperature. This is one of the significant advantages of the turbojet-ramjet compared with the straight turbojet. A related advantage is that the turbojet-ramjet could be extended to flight speeds higher than Mach 4 with less difficulty.

A possible Mach 4 turbojet-ramjet engine is shown in Figure 14. The gas generator has a higher pressure ratio than that of the straight turbojet since it was assumed to be optimized for a lower flight speed. The afterburner and nozzle are similar to that of the straight turbojet, but a bypass system which can pass air directly from the inlet into the afterburner is required. In the design shown, the same flow path from the turbine to the afterburner exists at all flight conditions. At a flight speed near Mach 3, a series of valves located around the periphery start to open and air from the inlet passes into the afterburner. As the flight speed increases, the bypass duct is opened further and the gas generator rotational speed is reduced so that a greater proportion of the air is supplied by the bypass. At some appropriate Mach

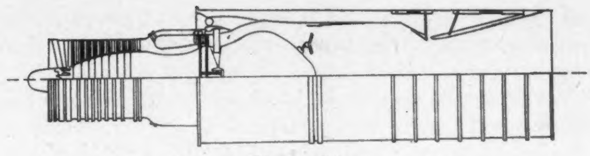


Figure 14
Mach 4 turbojet-ramjet engine

number the main burner of the gas generator is shut off and the gas generator then windmills at all higher flight speeds. No particular problems are expected for windmilling operation since the rotational speed will be low. The above method of achieving transition is not the only one possible but, no matter what method is used, the propulsion system must be controlled to protect the various parts of the powerplant and at the same time achieve reasonable performance. The added complication of this transition and related control is a disadvantage of the turbojet-ramjet compared with the straight turbojet which has a single mode of operation.

In order to compare the performance of the turbojet-ramjet with that of the straight turbojet, it will be assumed that the 7.5 pressure ratio gas generator of the turbojet engine, shown in Figures 10 and 11, is used in the turbojet-ramjet engine. The resulting performance comparison with the 5 pressure ratio straight turbojet engine is shown in Figure 15. The comparison is made on the basis of constant engine weight, with an appropriate penalty for valves and ducting. The turbojet-ramjet is sized for the same Mach 4 flow as the straight turbojet giving the flow characteristic shown in the upper portion of the figure. This is a degree of flexibility possible in the design of a turbojet-ramjet engine which is more difficult to achieve in a straight turbojet. The turbojet-ramjet engine has the better performance at Mach 4. This is associated with the 5% pressure drop assumed through the bypass valves and ducting of the turbojet-ramjet, compared with approximately 25% pressure drop through the turbomachinery of the

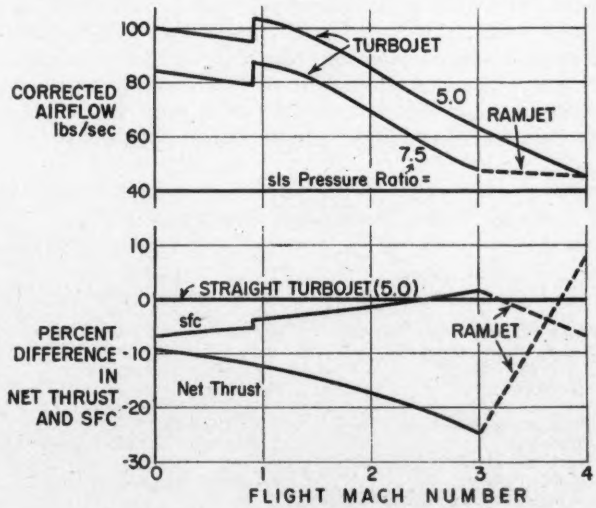


Figure 15
Performance comparison of turbo-ramjet with straight turbojet of Figure 7, constant engine weight basis

straight turbojet. At lower flight speeds, however, the turbojet-ramjet is inferior to the straight turbojet on a thrust/weight basis.

For large, long range vehicles, where cruise performance is of prime importance and where Mach 3 gas generators will soon be available, the turbojet-ramjet appears to have considerable potential. On the other hand, the straight turbojet would be attractive for small, short and medium range vehicles where simplicity and good acceleration thrust/weight ratios are important.

APPLICATIONS OF MACH 4 TURBINE ENGINES

Turbine engines are potentially useful for a wide variety of applications. A summary of these applications is shown in Table 1. Two broad categories are shown: the manned aircraft which usually call for large multiengine installations, and missiles which usually call for small single engine installations. Among possible military aircraft the long range bomber and the interceptor are now under development in the Mach 3 range. As the technology of aircraft design develops, it is very likely that similar aircraft will be considered for Mach 4 flight. It is probable that they will continue to utilize turbine engines because of the versatility of the turbine engine in powering the aircraft over the complete range of flight conditions, and in fulfilling the varying demands of manned aircraft.

Since all single stage chemical systems are limited in their range or in their burnout velocity, the concept of staging is resorted to for systems requiring close to or more than this limit. Since the initial part of any mission must be in the atmosphere, it is reasonable to consider an airbreathing engine for the first stage of a staged system. The turbine engine, being an efficient powerplant over the range of flight speeds from takeoff to Mach 4, is a very attractive powerplant for an airbreathing boost. A valid objection to an airbreathing boost is that of initial cost of the vehicle and engines. However, the incentive for the use of such a vehicle is that it can be made recoverable and reusable with very little penalty to the vehicle. Thus, the airbreathing boost is useful for work horse launchings where economy for a large number of launchings is important. The turbine engine is very economical from a fuel standpoint, since it uses a very small amount of fuel compared with a ballistic boost vehicle and the fuel it does use is relatively cheap. In addition, aircraft design philosophy will

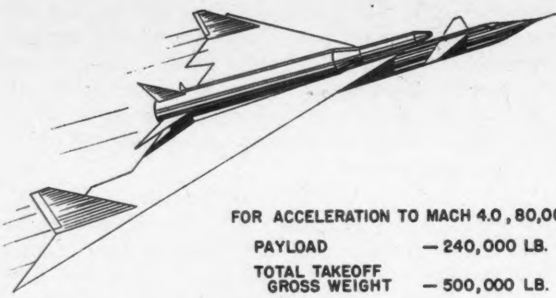


Figure 16
Example of an airbreathing boost vehicle

undoubtedly be used for an airbreathing boost vehicle, which will lead to a vehicle, including the powerplant, with the necessary endurance for numerous launchings.

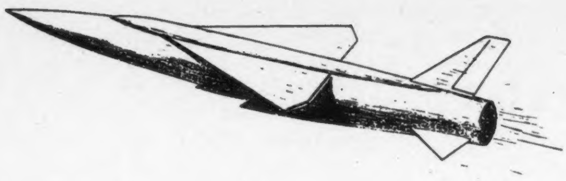
An objection sometimes cited against an airbreathing boost is that the thrust drops off with altitude. However, if the turbine engine is operated along the engine limit, as described earlier in the paper, the thrust is nearly constant over the operating range. An example of an airbreathing boost vehicle is illustrated in Figure 16. In this example the takeoff gross weight was set at 500,000 lb, which is high but within the range of experience with large aircraft. It is seen that payloads approaching 50% of the takeoff gross weight are indicated for an acceleration to Mach 4 and an appropriate altitude. This is better than any but the most optimistic ballistic type booster could achieve for an acceleration to the equivalent energy level. Since the airbreathing booster is useful for work horse type launching, normal takeoff from prepared runways would be utilized. In this case the total engine thrust required is still large, but could be fulfilled by 8 engines of 26,000 lb rate of thrust, for example. There usually will be a requirement that the vehicle achieve a certain altitude at the time the second stage is launched. The airbreathing boost is thus an application where high thrust at the maximum Mach number is desirable in order to perform the required maneuver with minimum loss of energy to the vehicle.

It is also appropriate to mention the commercial possibilities for Mach 4 aircraft powered by turbine engines. Supersonic transports in the vicinity of Mach 2 and higher are now being studied, and it is likely that some day they will look attractive enough to be bought. Once the breakthrough to supersonic commercial flight is made, it will always look attractive from range and vehicle utilization considerations to go to the highest possible Mach number permitted by the "state of the art" of aircraft design. Thus, the extension of commercial transports beyond Mach 2 to as high as Mach 4 is a definite possibility, especially if military aircraft lead the way. Such a development seems an order of magnitude more practical to the authors than the use of ballistic or boost-glide systems for commercial use.

The turbine engine powered cruise missile is a vehicle which the authors believe has a large potentiality. The intermediate range cruise missile will be taken up in this paper, but the characteristics described will also apply to other missiles. An example of a missile de-

TABLE 1
POTENTIAL APPLICATIONS FOR MACH 4 TURBINE ENGINES

Manned Aircraft (Large, Multiengines)	Missiles (Small, Single Engine)
Single Stage Military Aircraft: Long Range Bombers Tactical Aircraft Interceptors	Intercontinental Cruise Missiles
Airbreathing Boost for Staged Systems: Orbital Ascent Vehicles Glide Vehicles Long Range Ballistic Systems Staged Airbreathing Vehicles	Intermediate Range Cruise Missiles: Surface Launched Air Launched Submarine or Ship Launched
Commercial Transports	Interceptor Missiles



CRUISE L/D	6.0
RANGE	1500 n. miles
PAYLOAD & GUIDANCE WEIGHT	1500 lb.
ZERO LENGTH TAKEOFF ASSIST WEIGHT	500 lb.
TOTAL TAKEOFF GROSS WEIGHT	5000 lb.
TURBINE ENGINE TAKEOFF THRUST	2000 lb.

Figure 17
Example of an intermediate range cruise missile

signed for a range of 1,500 nautical miles and a payload of 1,500 lb is shown in Figure 17. With an assumed weight of 10% of gross weight for the solid rocket boost, the total takeoff weight of such a vehicle is 5,000 lb for the simple assumptions made in this paper. This is a striking difference when compared with the gross weights of ballistic missiles of this category. Note that a small turbine engine would be required for such an application.

The low gross weight of such a vehicle and its requirement for only modest launching equipment make it especially suitable for applications where mobility is important. In addition the missile uses conventional jet fuel, which is readily available and easily stored, which adds to the mobility feature. The cruise missile can be used from widely dispersed launching sites or from mobile surface launchers. Submarines and surface vessels also can take advantage of the small size of turbine engine powered cruise missiles. Since several cruise missiles could be carried in place of one ballistic missile, increased weapon effectiveness might be obtained when saturation of the enemy's defenses is considered. In the case of an aircraft launched missile, the low gross weight of the cruise missile results in a marked reduction in total system gross weight.

One of the areas in which the cruise missile has an advantage is that it is powered and controlled for its entire flight. This may allow more accurate guidance and also makes it easy to perform evasive actions with little complication to the vehicle design. Alternate missions are also possible with cruise missiles and, in particular, the vehicle can be directed to approach the target at a very low altitude to avoid radar detection. Another advantage is related not to the ultimate use of the missile, but to its long period of development and operational readiness. The missile can be designed to be recovered which should increase the economy of development and make possible many more test and training flights than would otherwise be possible.

A final advantage of turbine engines which holds for all applications is that it utilizes the experience both in industry and the military in the development, manufacture, operational use, and servicing of such engines. Because of this experience, a large return in weapon effectiveness should be possible from a given investment in time, manpower, and money. This is an important consideration when the demands upon the resources and economy of the free world are as heavy as they are today.

ROCKET RESEARCH IN CANADA†

by R. F. Wilkinson*

Canadian Armament Research and Development Establishment

SUMMARY

Some of the factors which have influenced the lines of the Canadian rocket propulsion research programme are discussed. The position of the rocket engine in relation to other propulsion devices is briefly indicated and the basic parameters governing rocket engine performance are given. A programme of applied research on case-bondable elastomeric propellants based on ammonium perchlorate and polymerizable fuel binder is described. Three rocket engines are being used, the largest being 17 inches in diameter and 17 feet long. The latter engine will form the basis of a test vehicle for studying propellants and also for use as a high altitude research vehicle. Some comments are made on possible advanced systems which may be considered for space missions.

INTRODUCTION

The Canadian rocket propulsion programme was re-examined in 1956 and it was decided to increase the effort with a programme of applied research as the main contribution. It is somewhat difficult to initiate a programme of this type without some knowledge of ultimate weapons applications and it was therefore necessary to narrow down the field somewhat. The Canadian Armed Services carry out a primarily defensive role and consequently some of the larger strategic offensive systems, such as the intercontinental ballistic missile, are not of direct interest. A primary interest is in systems of air defence for North America against such threats as the long range bomber and ballistic missile. In addition, there is an interest in weapon systems that may be used by the field Army and the Navy.

In addition to contributing to the defence programme of applied research it was considered essential to produce a group of experts in this field which could assist in weapon systems studies and give advice to the Armed Services to assist them in making the correct decisions as to which weapon systems they should acquire. It was also felt that limited production facilities for rocket propellants should be set up in Canada so that the early small scale requirements for Canadian-produced missiles could be economically met. Larger scale production would, of course, be met by Canadian Arsenals Limited or other industrial sources.

The programme of work that was started is now well advanced. The laboratory and smaller scale work has made considerable headway and the larger scale processing facilities are now almost complete. The purpose of this paper is to give, within security limitations, a general outline of the Canadian programme and its aims and to indicate some of the thinking behind it. To do this, the first part of this paper is devoted to some general background related to the problems of improving the performance of rocket engines.

THE POSITION OF THE ROCKET IN THE PROPULSION FIELD

It is not intended to discuss in great detail the relative merits of the various jet-propelled devices, but a few words about the relation of the rocket to other devices might be appropriate. All these devices operate on the basis of a rather simple equation:

$$F = V\frac{dm}{dt}$$

where F = force, t = time, m = mass and V = velocity

This equation states that any change in momentum (mV) in a time t, is accompanied by a force (F). The rocket, ramjet, pulse jet and turbojet are all based on this equation. In all cases, gases at high velocity are expelled backwards, producing a forward thrust. The rocket differs from the other devices in carrying its own oxygen instead of using the oxygen of the air to promote combustion. This difference is quite fundamental and governs generally most of the advantages and disadvantages of the rocket.

The pulse jet and ramjet have the advantage of being relatively simple to manufacture and relatively cheap, but are limited by the necessity for boosting to the operating velocity before the engines will work and also by the need to remain in the relatively dense atmosphere for oxygen supply. The pulse jet is not suitable for very high velocities but the ramjet is.

The turbojet has been developed into a very efficient engine for some operating conditions in recent years and it is very reliable. Its maximum speed is limited to about 1,500 mph and it must operate in the denser part of the atmosphere to maintain the oxygen supply.

The great advantage possessed by the rocket engine is that it carries its own oxygen and does not depend on the oxygen of the atmosphere. In fact it operates at its greatest efficiency in the vacuum outside the atmosphere. Its speed can be made extremely high and the developed power is phenomenal. While there are applications for all these propulsion systems, the rocket has indisputable claims to long range missiles travelling in

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 7th October, 1958.

*Superintendent, Explosives Wing.

space and to other shorter range missiles where high speed, acceleration and power rating are required.

ROCKET THEORY

All rockets are based on controlled chemical reactions in an enclosed space called the combustion chamber, leading to the rearward expulsion of high velocity gases. In a perfectly efficient rocket engine, all the chemical energy that is released is converted into kinetic energy of motion of the gases out of the nozzle. An important parameter governing rocket performance is the adiabatic flame temperature (T_c) of the propellant. This can be calculated from the data on the heats of formation (H_f) of the reactants and products and the specific heat (C_p) data of the products:

$$H_{f\,(\text{products})} = H_{f\,(\text{reactants})} = \sum n_p \int_{T_o}^{T_c} C_p \, dT$$

where n_p = number of moles of product

T_o = ambient temperature

By successive approximations from the equilibrium concentrations of products at various temperatures, T_c can be calculated. Two other important parameters, the mean molecular weight (M) and mean specific heat ratio (γ) of the product gases, can also be obtained easily. Using these three parameters a figure representing overall propellant performance can be calculated. This figure is the specific impulse (I_{sp}) which is measured in units of pounds (force) seconds per pound (weight) of propellant and is given by the following fundamental rocket equation:

$$I_{sp} = \sqrt{\frac{2g\gamma}{\gamma - 1} \cdot \frac{R' \, T_c}{M} \left[1 - \left(\frac{P_o}{P_c} \right)^{\frac{\gamma - 1}{\gamma}} \right]}$$

where g = gravitational constant

R' = gas constant

P_o = ambient pressure at nozzle exit

P_c = chamber pressure

It can be seen that when the rocket is operating in a vacuum $P_o = 0$ and the equation reduces to:

$$I_{sp} \propto \sqrt{\frac{T_c}{M} \cdot \frac{\gamma}{\gamma - 1}}$$

which indicates that, for maximum performance, the chamber temperature must be a maximum and the mean molecular weight and specific heat ratio must be a minimum. The chamber temperature is usually in the range of 2,600-3,200°C, the mean molecular weight about 22 and the specific heat ratio about 1.25. The molecular weight parameter imposes serious limitations on the choice of propellant materials and present systems usually produce products consisting principally of H_2O, CO, CO_2, N_2 etc. More advanced systems are limited to the lighter elements such as lithium, boron, aluminum etc. The chamber temperature is usually limited by materials of construction and the design of cooling systems. The specific heat ratio is not a very critical factor. Figure 1 shows some typical relationships for an expansion ratio $\left(\frac{P_c}{P_o}\right)$ of 40 and a specific heat ratio of 1.25.

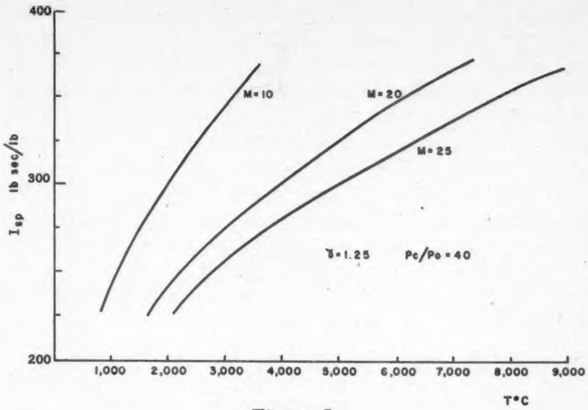


Figure 1

The specific impulse gives a measure of propellant performance and is proportional to the exhaust gas velocity. The performance of the rocket itself is governed by its mechanical design and is greatly dependent upon the ratio of the burnout weight to the total weight of the rocket, as shown by the following equation:

$$V = gI_{sp} \ln \frac{W_2}{W_2 - W_1}$$

where V = burnout velocity

W_2 = total weight

W_1 = propellant weight

This equation represents an ideal situation since it neglects gravitational effects and drag produced by the atmosphere. Figure 2 shows the effect of the mass ratio $\frac{W_2}{W_2 - W_1}$ and specific impulse on burnout velocity. It is worth remembering that the earth escape velocity is 36,700 fps and the 300 mile satellite velocity is 24,200 fps. It is clear that it is difficult to achieve these velocities with single stage rockets and the reason for the use of multi-stage rockets, such as with Vanguard and Explorer, is obvious.

THE LIQUID ROCKET ENGINE

In the liquid rocket engine the fuel and oxidant, which must usually be kept separate, are stored in

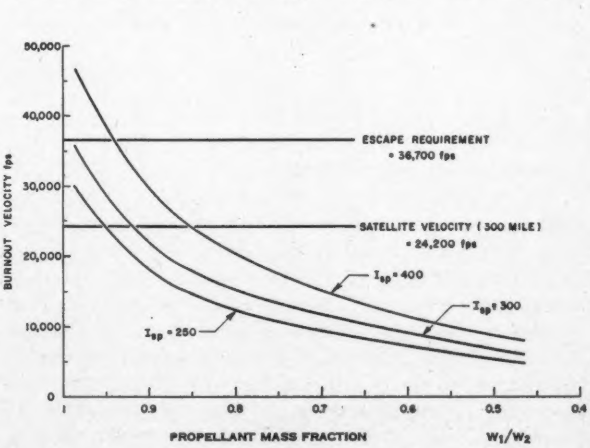


Figure 2

separate tanks. These liquids are then transferred under pressure to the combustion chamber which can be kept relatively small and cooled by circulating the fuel through the walls. The liquids are pressurized either by a gas reservoir or by high capacity turbine pumps in the bigger rockets. These pumps need to deliver as much as 1,000 gallons per minute in some of the larger rockets and must be driven by some source of gas. The principal advantages of liquid rockets are that high specific impulse can be obtained and that thrust vector control and thrust termination are relatively simple. Some typical comparative propellant performance figures for various liquid systems are shown in Table 1.

TABLE 1

LIQUID PROPELLANT PERFORMANCE AT 500 PSI

Oxidizer	Fuel	I_{sp} lb sec/lb	T_c °C	M	γ
Red fuming nitric acid	Aniline	235	2820	–	–
	Ammonia	237	2320	21	1.24
	JP-4	240	2850	25	1.23
	Unsymmetrical dimethyl hydrazine	250	2890	22	1.23
Hydrogen peroxide (99%)	Ethyl alcohol	240	2540	23	1.24
	Hydrazine	262	2590	19	1.22
	JP-4	248	2660	21	1.20
Liquid oxygen	Ethyl alcohol (75%)	247	2850	23	1.22
	JP-4	264	3200	22	1.24
	Hydrazine	280	2970	18	1.25
	Hydrogen	364	2480	9	1.26
Liquid fluorine	JP-4	280	3930	24	1.22
	Ammonia	306	4000	19	1.33
	Diborane	310	–	–	–
	Hydrazine	316	4400	19	1.33
	Hydrogen	373	2820	9	1.33

It can be seen that most usable systems give specific impulses in the range 235-280 and this is the presently attainable range. Improvements are only brought about by the use of liquid fluorine or liquid hydrogen. Fluorine is attractive because of the greater energy release and hydrogen because of the low molecular weight of the products. Both are difficult materials to handle and, in addition, hydrogen has a very low density.

All liquid rocket engines suffer from unreliabiltiy caused by great complexity and usually require a considerable time prior to launching for loading oxidizer and fuel and checking out. Some recent firings of large liquid rocket engines have emphasized these difficulties which still exist, although 12 years have elapsed since the successful use of the V2.

THE SOLID ROCKET ENGINE

The solid rocket engine differs from the liquid engine primarily in having all the fuel and oxidizer in the combustion chamber, resulting in a much larger combustion chamber which must be designed to withstand the chamber pressure. This design feature has, for many years, limited the mass fraction of propellant in the solid rocket and made them relatively inefficient. However, recent engineering advances in the design of high strength steel cases and improvements in the physical properties of propellants have made possible great improvements in overall performance and the two types of engines are now competitive. The actual performance or I_{sp} for solid propellants at present available is generally in the range of 200 to 240 pound seconds per pound of propellant and the theoretical maximum for propellants based on carbon, hydrogen, oxygen and nitrogen as the prime ingredients is about 250. There are, however, several possible improvements in sight but it is unlikely that solid propellants could reach I_{sp} levels as high as the best of the liquid systems, i.e. above 300, in the foreseeable future. Apart from performance considerations the advantages of the solid propellant rocket are obvious. The whole system is relatively cheap to manufacture, reliable in operation, and involves very short preparation times in the field. The problems of thrust vector control and thrust termination are more difficult than with liquid engines but these problems should be surmountable.

CANADIAN PROGRAMME

Propellant development

In view of the Canadian defence interests outlined in the introduction, there is little difficulty in reaching the conclusion that the Canadian programme should be based primarily on solid propellant rocket engines. For air defence against ballistic missiles and high speed aircraft, the warning time is uncomfortably short and an instant state of readiness for the defensive missiles is essential. For use of the field Army and on ships the logistic problems of handling liquid oxygen or nitric acid appear to be overwhelmingly difficult. All these factors are heavily in favour of solid propellants even if some weight penalty may have to be paid.

As pointed out above, the outstanding improvement in the performance of solid propellant rocket engines in recent years can be attributed to a large extent to the development of case-bonded grains in contrast to the free-standing grains previously used. The difference is illustrated in Figure 3. The loose-filled grain is fabricated outside the rocket engine case and is usually inhibited on the outside surface so that burning occurs only on the inner surface. It is then necessary to support the grain mechanically within the case to withstand the various accelerations to which it is subjected during and after launch. In addition, hot gases come in contact with the walls of the case. The net result is a heavier case and

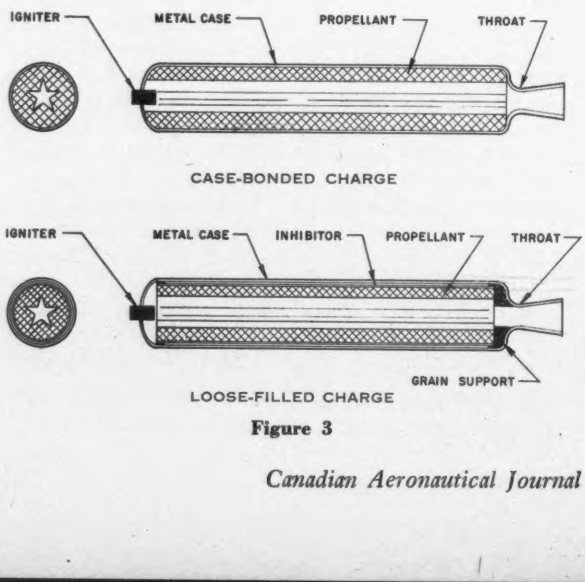


Figure 3

considerable weight in the form of ancillary hardware. With the case-bonded propellant, the outer surface of the propellant is bonded to the case which is thus kept cool until the instant of burnout, allowing a considerable weight reduction. Another advantage is that the propellant mass is supported over the entire inner surface of the case and the entire load during acceleration need not be supported at the rear end as with the free-standing grain. In view of these considerations the Canadian programme was confined to case-bondable propellants which can be cast directly into the case.

A considerable amount of effort has been directed towards improvements in the physical properties of the propellant so that it can withstand all the necessary environmental conditions. These include the wide temperature range which ammunition must normally be capable of withstanding and the various accelerations to which it is subjected. These problems become progressively more critical as the size of the rocket grain increases. Other considerations require that the propellant must not be degraded during prolonged storage under adverse conditions, it must not be unduly hazardous to manufacture or handle and it must preferably be made from materials which are commercially available and indigenous to Canada.

It was decided not to use the family of propellants based on nitrocellulose and nitroglycerine since it was considered that they possessed limitations which would make it extremely difficult to meet some of the requirements. Attention was therefore concentrated on propellants based on a solid crystalline oxidizer and an organic polymerizable binder. The choice of convenient oxidizers is limited to ammonium nitrate, ammonium perchlorate or potassium perchlorate. For various reasons ammonium perchlorate was selected. To achieve satisfactory performance, it is then necessary to use 75-80% of this oxidizer with 20-25% of a fuel based on carbon, hydrogen, oxygen and nitrogen. If the propellant is to be castable the choice of binder or fuel is then limited and care must be taken to use the optimum oxidizer particle size distribution.

The binders selected for the initial work were based on polyurethane rubbers. The rubbery nature of the material over a wide temperature range ensures that the stresses developed during temperature changes are kept to a minimum. The specific impulse of the propellants that have been developed is in the range of 220-235. Work is in progress which should lead to considerable improvements in performance with similar types of propellant. This work involves principally the use of various additives, such as aluminum powder or boron compounds.

Rocket engines

The propellant development work is being done with two small rockets about 8 inches in diameter, one about 4 feet long and the other about 8 feet long. These are being used for the determination of the ballistic characteristics of the propellant, such as burning rate and specific impulse, and also for a study of the effect of temperature variations. Burning times of 6-8 seconds and thrusts of 2,000 lb are obtained with the shorter engine. Both are relatively thick-walled and will be used only for static testing.

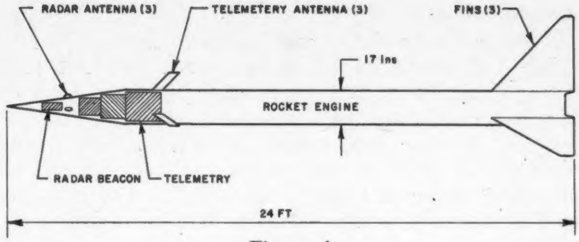


Figure 4
Propulsion test vehicle

The second stage of the programme will use a much longer engine about 17 inches in diameter and 17 feet long. It will contain about 2,000 lb of propellant and give a thrust of about 20,000 lb for about 20 seconds. The engine will first of all be used for developing processing techniques for larger rocket engines but it has a thin-walled case and will be used for dynamic firings in a test vehicle programme.

The test vehicle

The 17 inch engine will be used to propel a test vehicle[a]. The general layout of the vehicle is shown in Figure 4. Early firings will be at the relatively low elevation of about 70° and will be used primarily to assess propellant performance under dynamic conditions. A considerable amount of information on propellant and vehicle performance will be transmitted back to the ground by a telemetering system. Later firings will probably be done at near vertical elevation to utilize the vehicle as a high altitude research vehicle. It will carry a payload of 100 lb or more to an altitude of 80-100 miles.

Manufacturing and testing facilities

Comprehensive facilities have been established for manufacturing and testing rocket propellants. The plant is relatively small in capacity but is capable of handling rocket engines which are considerably larger than the 17 inch engine and is one of the most modern. Static test facilities are available for testing large rockets, as are facilities for conditioning the rockets at either high or low temperatures before firing.

ADVANCED PROPULSION SYSTEMS

No paper on rocket propulsion would be complete without some discussion on the subject of advanced propulsion systems. In this category may be included those systems which are capable of yielding performance better than that obtainable from conventional chemical systems, which appear to have a fundamental performance limit of specific impulse in the range of 300-350 pound seconds per pound. It is unlikely that these systems will find extensive application in armament engineering for many years but they are of great interest as applied to the problems of artificial satellites and space flight. Research is likely to continue at a high level to solve the many problems involved.

[a]The test vehicle is being designed and constructed under contract with the Defence Research Board by Bristol Aircraft Limited in its Canadian and United Kingdom facilities.

Nuclear rockets

Nuclear propulsion would, at first sight, appear to offer great attractions. However, certain difficulties soon become apparent. The propulsion principles outlined above are still applicable and performance is still dependent on the temperature, molecular weight and specific heat ratio of the working fluid. It is therefore necessary to obtain a reactor at a very high temperature and to carry the working fluid in addition to the weight of the reactor itself. Hydrogen or possibly ammonia are the only working fluids which appear to be attractive. The heat transfer problems at high temperature are immense but, on the other hand, it is possible that the safety and reliability standard of power reactors may be reduced considerably. Significant advances are still required in the development of materials of construction before great headway can be made, but this type of system will undoubtedly become more and more attractive to meet the requirements of space travel which involve the development of power over long periods of time.

An alternative approach is the use of a homogeneous gas phase cavity reactor in conjunction with a working fluid such as hydrogen. The practical problems appear to be immense and a reasonable solution does not yet appear to be in sight.

The use of pure fission energy for propulsion does not appear to be possible since no reasonable method of directing the fission fragments in a selected direction yet appears to be possible. If half the products travel rearwards and the remainder is absorbed in the structure of the vehicle, immense temperatures would be realized in the structure.

Free radicals

The utilization of the energy associated with free radicals, such as CH_3, CH, H etc, is fundamentally attractive and with a working fluid, such as hydrogen, specific impulses in excess of 400 are theoretically attainable. However the practical problems of producing, isolating and maintaining these radicals have not yet been solved and it is clear that much basic research will be necessary before this principle can be exploited.

Solar rockets

The principle of using the sun's energy to heat the working fluid is attractive in principle. For instance, if hydrogen can be heated by the sun to a temperature of 2,800°C, a specific impulse of 900 can be achieved. There is a practical problem of designing a suitable collector for the sun's energy and transferring this energy to the working fluid. These problems might well be solved given sufficient time and effort.

Ion propulsion

Ion propulsion is based on the ionization of a suitable atom, such as caesium, into positively charged ions and electrons. The electrons are collected within the rocket and the positive ions are ejected at the rear of the rocket after electrical acceleration to a high velocity. This principle is sound but the practical difficulty is the design of a source of electric power which can supply the large amounts needed for the ionization and positive ion acceleration. With the great advances to be expected in the development of compact nuclear reactors, this type of system may well become attractive for supplying low thrusts over long periods of time.

Photon propulsion

The radiation pressure associated with a hot surface has frequently been mentioned as a source of space propulsion. However our present technology is quite incapable of handling the fantastic temperatures (10^8 °C) required to supply a few pounds of thrust.

CONCLUSIONS

Canada has now established itself in the rocket propulsion field and is capable of meeting any foreseeable requirements for conventional chemical fuel systems. A significant contribution is being made to the development of improved solid propellants and a high altitude research vehicle capable of carrying significant payloads to altitudes of about 100 miles should soon be available.

A superficial study of the feasibility of advanced propulsion systems based on nuclear reactors, free radicals, solar energy, ions or photons indicates that there are many problems requiring solution before the performance of conventional chemical rockets can be exceeded. However, with concentrated research effort and technological advances in the use of materials of construction, it may be expected that at least some of these systems will find application in meeting the requirements of long distance flight and space travel. The solar rocket or thermal nuclear rocket probably offer the best hope of success.

BROAD OUTLINE OF AIRCRAFT FEEL – PILOT'S APPRECIATION†

by W. J. Potocki*

Avro Aircraft Limited

INTRODUCTION

In this paper I propose to describe generally, and to discuss briefly, various types of feel in aircraft, ranging from simple subsonic types to the recent high speed supersonic machines. The subject is as yet controversial and the field of interest extremely wide. It is therefore beyond the scope of this paper to attempt a detailed study of the associated problems, even in part. The intention is to consolidate from the pilot's point of view the principles underlying the understanding of aircraft feel. As the control of the modern aircraft is primarily a two axis (pitch and roll) control, the ensuing discussion will be dealing mainly with the elevator and aileron systems.

The author wishes to acknowledge the advice given to him in the preparation of this paper by several members of the Engineering Division of Avro Aircraft Limited; however, the views presented here are the personal views of the author and not necessarily those of the Company.

The Pilot

Before feel of aircraft is discussed, it might be useful to introduce some information about the pilot. We know from practice that *in simple tasks* the difference in performance between one pilot and another is generally small, becoming perhaps negligible when a comparison in this case is made of repetitive performances of one individual. As the task is gradually stepped up, the pilot becomes suddenly complex and somewhat inconsistent in his operation[1]. Then at each progressively more difficult stage the overall performance will depend on the varying measures of adaptability in pilots, the degree of predictability of the system they operate, their individual nervous and muscular characteristics and also their psychological and physiological set at the time of operation[2]. In spite of all this, the servo systems engineers agree that a price of 90 cents (which apparently is the price of the chemicals in the human body) is not too high to pay for such an adaptive servo. A human, however, appears to have some limiting characteristics which have been found to remain basically unchanged. They are his reaction time (normally between 0.2 and 0.3 sec) and his neuro-muscular lag (0.1 to 0.16 sec). "These unalterable characteristics of the human represent his most serious liabilities as a servo element and restrict system performance."[2] The investigators into a human pilot as a mechanism, in order to simulate his characteristics on the computers, try to find a common expression for a so-called "equalizer" – an individual quality which in the human system modifies the stimulus signal command and appropriately adjusts it to suit best the control of a particular dynamic device. Then there is a "remnant" and a "dither". The former is classified in part as pilot's noise or random error and the latter perhaps could be described as individual gesticulations with controls in addition to those necessary to effect desired response, particularly in a difficult program.

This brief description of factors inherent in a pilot's performance suggests that there are limits outside which his adjustment may deteriorate to a point where it becomes unreliable. The requirements relating to flying qualities of piloted aeroplanes which are written primarily on the basis of past experience, but also no doubt on human response studies, take these limits into account and define certain criteria and boundaries within which a reasonable assurance of satisfactory characteristics of pilot-aeroplane combination should be obtained in practice. In the main they relate the aircraft responses to pilot's forces and control deflections in various stages of flight, and thus set up a broad pattern for desirable aircraft feel.

LIST OF SYMBOLS

α	angle of incidence (attack)
α_T	stabilizer angle of incidence
a_1, A_1	stabilizer lift effectiveness $= \frac{\delta CL}{\delta \alpha_T}$
a_2, A_2	elevator lift effectiveness $= \frac{\delta CL}{\delta \epsilon}$
β	sideslip angle
b_1	hinge moment coefficient at constant elevator $= \frac{\delta CH}{\delta \alpha_T}$
b_2	hinge moment coefficient at constant incidence $= \frac{\delta CH}{\delta \epsilon}$
CM_0	pitching moment of wing at zero lift
δa	aileron angle
$\delta \epsilon$	elevator angle
δr	rudder angle
F_S or SF	stick force

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 8th October, 1958.

*Chief Experimental Test Pilot.

F_R	rudder force
g	normal acceleration
K	response factor $1 + \dfrac{b_1 \times \Delta a_T}{b_2 \times \Delta d\epsilon}$
σ	relative density
P	rate of roll
R	total damping in pitch
V_i	equivalent airspeed $V_i = V \times \sqrt{\sigma}$

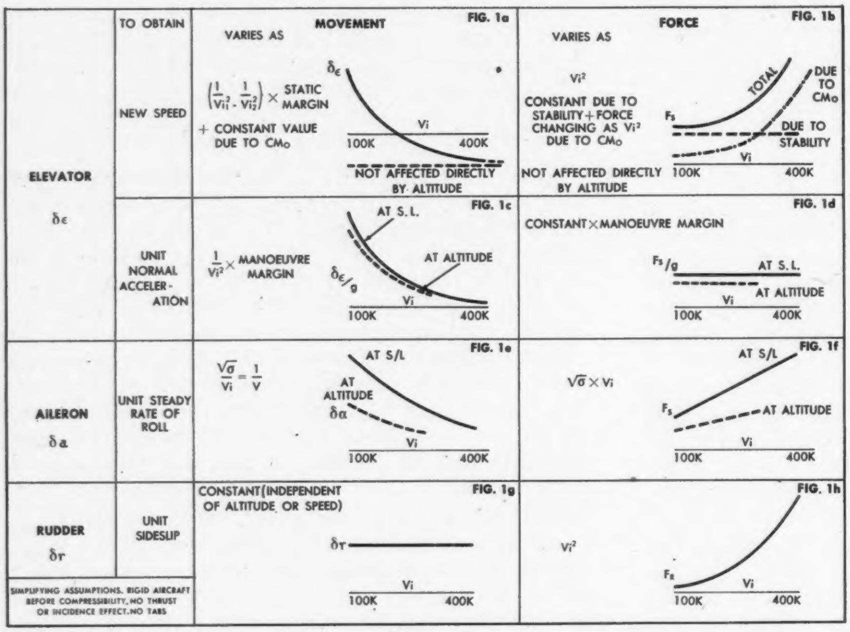


Figure 1
Relationship of control movements and forces in steady state responses (simplified subsonic aircraft)

WHAT IS AIRCRAFT FEEL?

It is probably true to say that, with regard to the intended flight path, no aircraft is ever in a state of absolute equilibrium. The range of path control is contained between, on the one hand, extreme closeness to this absolute and, on the other, a violent transient manoeuvre which is restricted only by the pilot's will, human physiological factors, aircraft life capability, control authority or structural strength. The degree of smoothness and accuracy over this very wide spectrum of possible path control in the presence of numerous external disturbances, aircraft changing stabilities and varying aircraft, as well as human responses, is dependent on the quality of the functional link between the man and his machine. This link is the aircraft feel.

FROM MANUAL TO POWER OPERATION

Steady state responses

The feel in manually controlled aircraft was derived mainly from control forces arising from hinge moments of controls. The control movements were also of importance but to a lesser degree and only became of paramount interest when we were running out of con-

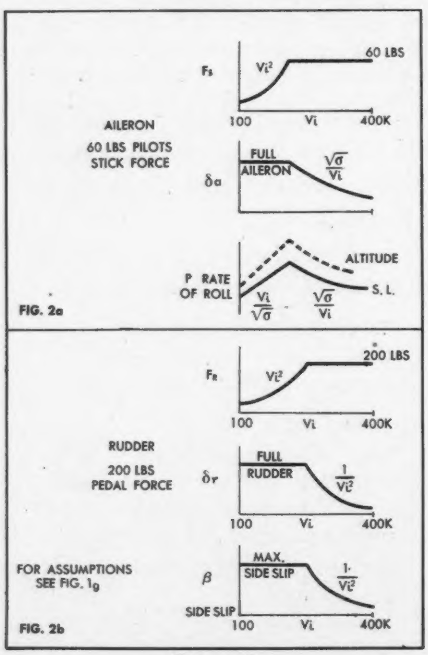


Figure 2
Limits of steady aircraft responses as created by mechanical stops or human force limits

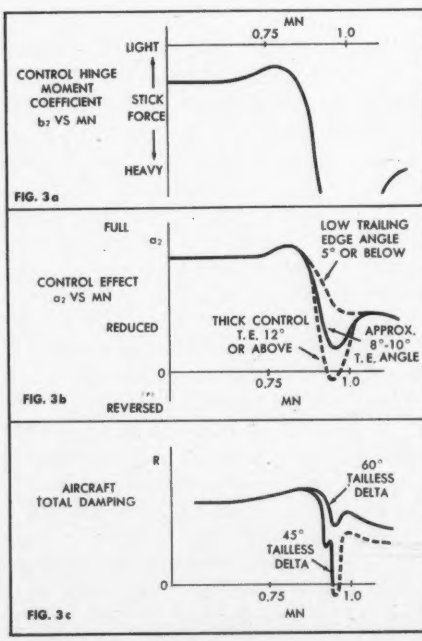


Figure 3
Effects of Mach number on b_2, a_2 and R

trol. The trend of control movement for steady responses was a function of $\frac{1}{V_1^2}$ for elevator and $\frac{\sqrt{\sigma}}{V_1} = \frac{1}{V}$ for aileron. The forces generally increased with speed in steady straight flight (assuming no retrimming) as V_1^2 on elevator and rudder, and $V = \sqrt{\sigma} \times V_1$ on aileron for steady rate of roll (Figures 1 and 2). The fall of control effectiveness at Mach numbers past critical and the aeroelastic effects tended to offset hyperbolic decrease of control angles with speed. The control forces in this speed range were more seriously affected, primarily because of rapid increase in hinge moment coefficients with Mach number and secondly because of fall of control effectiveness.

These two effects would often come in rapidly, requiring for small increments of Mach number forces sometimes several times higher than those below critical Mach number (Figure 3). To this, of course, was added the aeroelastic problem, but its effect was somewhat more gradual.

The above phenomena soon created serious feel problems near maximum operational speeds. The aircraft response was seriously restricted by heavy control forces which, combined with rapid changes in aircraft stability, often became erratic, the accuracy of flight path became impaired and the task of the pilot, bordering on the limits of his force capability, quite tiresome.

The art of control balancing had a great part to play in keeping these forces at a reasonable level, but one might say that it had already been developed to the practical limits before the Mach number effects became truly significant. To meet control safety requirements in service, early jet aircraft in some cases had speed limitations imposed on them well inside their maximum performance.

With further increase of performance, larger control surfaces had to be introduced to offset the fall in control effectiveness with Mach number and these could not be balanced sufficiently to maintain the forces at reasonable levels.

The pilot was given the assistance of hydraulic boost which effectively meant that he became in relation to the aircraft that much stronger. Now he had a reasonable command at higher speed, but at the lower speeds the control force level was often low and tended to make control rather too light, particularly in swept wing aeroplanes.

As the performance increases continued and near supersonic speeds were reached in level flight, the degree of hydraulic boost became such that the next logical step was to reduce the control feedback altogether and introduce full power operation.

Transient responses

So far only steady state responses have been considered. Because of the final inertia of the aircraft the steady response is not realized instantaneously. Considering, for example, a case of rapid straight pull up, a noticeable time lag is invariably present between the control application and the final g response. This time lag depends mainly on the aircraft stability, and its inertia in pitch. In the absence of aerodynamic damping, this response prior to steady state would be oscillatory with several reversing overshoots (Figure 4). In practice, particularly in the case of subsonic tailed aircraft which are heavily damped, the entry into steady response is virtually without overshoot.

The effects of Mach number in the transonic region generally resulted in less aerodynamic damping. The experience showed this to be true even in conventional configurations, but noticeably more so in tailless or small tail arm aircraft, particularly at altitude. Consequently, the transient manoeuvre required more anticipation, thus affecting accurate feel adversely.

The author recollects oscillatory motions of a manually controlled delta in the transonic region where heavy and reversing stick forces, resulting from a tendency of control to align itself with the relative wind during the oscillation, presented him with a difficult task in an attempt to stop it. The periodic time was such that normally one would expect control possible. However, the heavy and reversing forces tended to create such phasing between the aircraft and the pilot that oscillation persisted. In a powered control version of this aircraft, the oscillation due to low damping was still present but because the control was irreversible and the force level was lower due to artificial feel, the pilot felt more in control.

It is worthwhile to add here that in an extreme case of poor damping, to achieve the steady state response quickly without aircraft oscillation, the pilot would be required to provide his own damping, which implies an

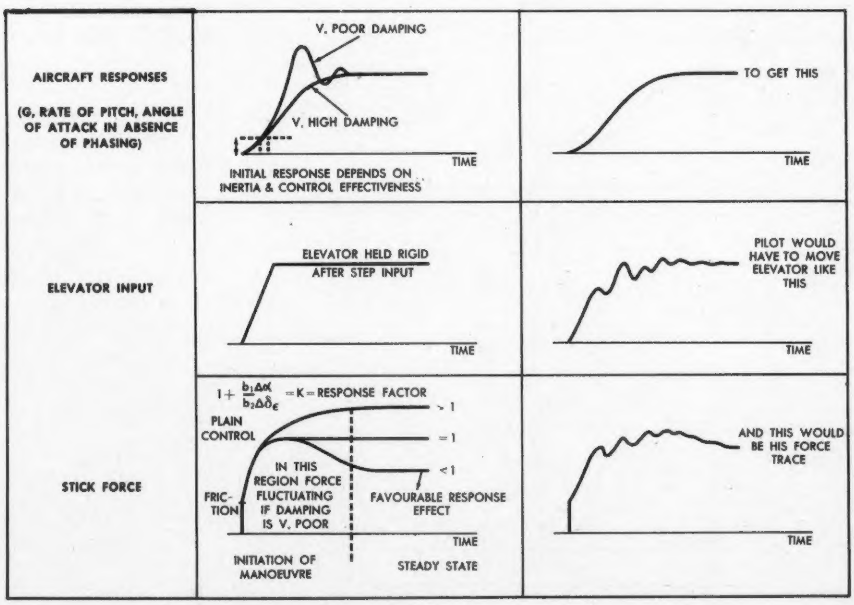


Figure 4
Transient response characteristics to elevator step input simplified aeroplane as in Figure 1

Figure 5
Hypothetical case of idealized response in case of very poor damping

oscillatory control input (Figure 5). This, in practice, is not possible. The "black boxes" can be designed to deal with this problem better than a human can.

SUPERSONICS

It has been mentioned earlier that flight into the transonic region in aircraft not designed for supersonic penetrations was often marred by control and stability problems. In the machines built for sustained supersonic flight and power operated, these have been substantially reduced primarily through lowering of the force level. Supersonic flight, however, gives rise to other complications. Because of high drag and fuel consumption and also structural weight penalties which would have had to be met to avoid excessive aeroelastic problems at low altitude, high altitude became the area of sustained supersonic flight. Here, however, the relationship between the aircraft momentum, which is dependent on its true speed, and the restoring or controlling forces, which are proportional to comparatively low dynamic pressure, influences adversely the dynamic stability and controllability. Statically, there are large trim changes in going through, mainly due to the aerodynamic centre shift to approximately ½-chord and the downwash reduction, followed by generally unstable trim tendency with Mach number at constant altitude. The reduction of control effectiveness to approximately 50% of its subsonic value calls for higher control deflections in manoeuvring flight (Figure 6).

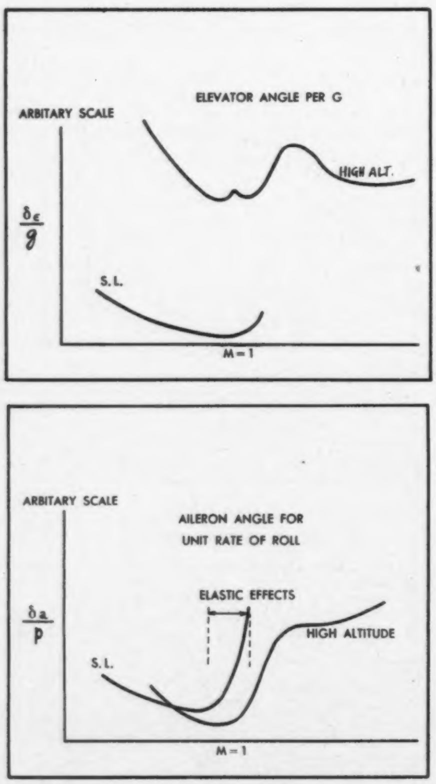


Figure 6
Supersonic effects on elevator angle and aileron angle to obtain steady state response

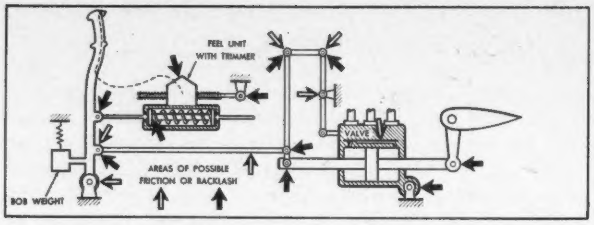


Figure 7
Schematics of a power control system

This sketchy picture is, of necessity, grossly simplified and is only introduced to point out that there is a noticeable difference between subsonic and supersonic flight, the latter tending towards decreased sensitivity of the aircraft's initial response to control whether in commencing or arresting it, a general fall in damping and the need for larger control displacements. It will be seen later that these factors complicate the compromise which the design must achieve to equip a given aeroplane with an artificial feel suitable for both subsonic and supersonic regions of operation.

POWER CONTROLS (HYDRAULIC)

Characteristics of various elements of power control system as related to feel

A power control system in aircraft can be compared with an enormous amplifier with the output to input ratio running into thousands to one, limited only by the geometry of the jacks and the system flow rate and pressure. Basically there are five major components inserted between the pilot and a control surface, as follows: Control (stick or rudder bar); Feel Unit; Linkage (including gearing); Valve; and the Jack with follow-up linkage (Figure 7). Each of these has something to contribute towards feel of a particular aircraft. This contribution results from the fact that the pilot's command demanding a transfer from static to dynamic state is made through interplay of frictional, inertial and viscous forces present in the appropriate element of the system. In addition, there may be lost motion.

When assessing a particular aircraft feel, the pilot would be required to investigate certain salient features which appear common to all power control systems and which can influence the feel quality to a large extent. They are as follows:

Break-out force
Back-lash (or lost motion)
Self-centring
Gradient of stick force vs stick displacement

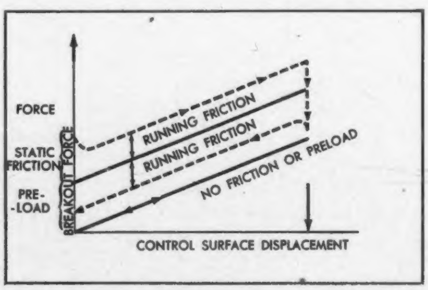


Figure 8
Break-out force effects

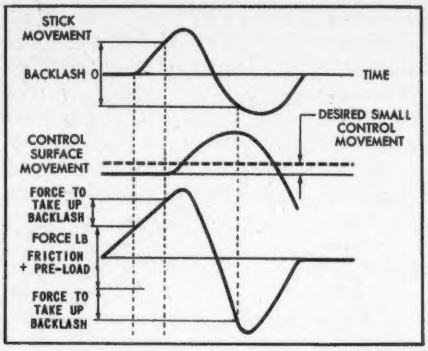


Figure 9
Backlash and friction effects on small control application

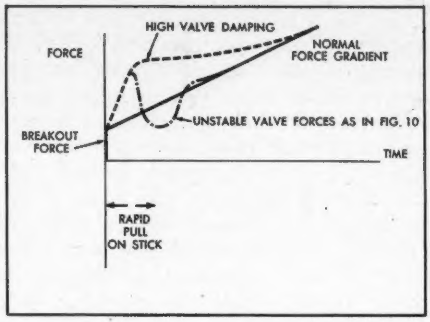


Figure 11
Forces during rapid stick application

- Ratio of control surface displacement to pilot's stick movement
- Trim quality
- Range of trim
- Stick damping on release after displacement
- Rate damping in rapid stick movements
- Any other features (oscillatory motions, valve damper effects etc.)

Some brief notes on each of the above will now be given:

***Break-out force* (Figure 8[3])**

This term defines the force necessary to be applied to the stick before it will begin to move. The source of it lies in the accumulative effect of all of the following: (a) the mechanical friction of the control circuit, the feel unit and the valve; (b) the force due to the viscous flow past the valve in its neutral position and/or valve centring spring, and finally (c) the pre-load of the feel unit.

If this force is high, it will tend to produce overshooting in the desired small and rapid control applications (e.g. tracking or instrument flight) because of the previously mentioned pilot's neuromuscular and reaction lag, as the pilot's pressure on the control to overcome this force will be likely to continue during that short period and take the control past the desired value (Figure 9[3]). These effects will be aggravated if the force level immediately following break-out force becomes noticeably lower due to poor valve dynamics (Figures 10 and 11) or, what is usually the case, a lower running friction.

If the initial aircraft response is slow and much damping is present, it is likely that the effect of this overshoot would be negligible; however, rapid aircraft response to control application will result in marked and undesirable overshoot, often culminating in pilot induced oscillations.

Backlash

Backlash is a result of mechanical play somewhere in the control circuit to the valve. An "apparent" backlash can result from large valve overlap (Figure 12(a)). There is also "feel" backlash, resulting from lost motion within the feel unit and also in the attachment of feel unit to the stick assembly.

(a) Valve force characteristics

(b) Valve rate spring and damper schematics

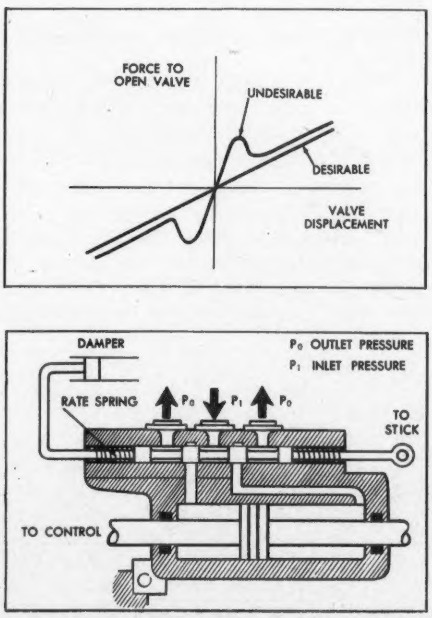


Figure 10

(a) Valve overlap and valve underlap

(b) Valve flow characteristics

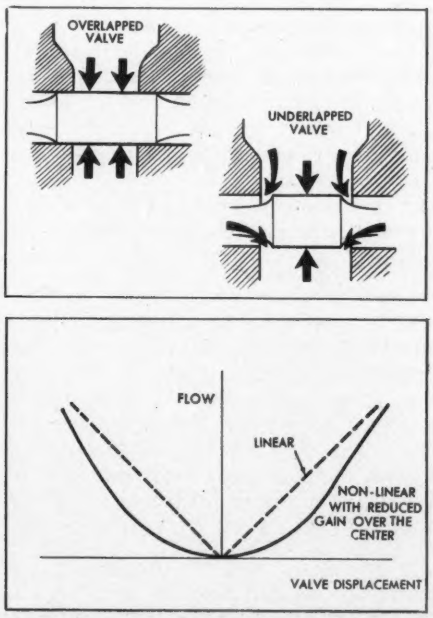


Figure 12

In the first two cases the stick will move after overcoming of break-out force and then, as the play or valve overlap is taken up, an additional break-out force will appear before any aircraft response is noted. In the last case, after breaking through the static friction of the circuit or valve (the design aim being to keep them as low as possible) the control surface will move and give aircraft response, before any effect from feel unit is felt by the pilot. These low forces within the "feel" backlash have been known in the past to result in sudden aircraft response virtually without any indication to the pilot that the control was being applied, giving in highly responsive aircraft very erratic behaviour with the pilot's control near the neutral position, particularly at high indicated airspeeds.

Self-centring

The degree to which pilot's control and the surface will tend to return to neutral after it has been displaced is termed self-centring. If there were no friction and no backlash, the centring of control upon the application of centring force would be perfect. However, in practice, there is friction and there may be some backlash, and both of these will tend to upset self-centring.

To deal with de-centring effects of friction, the feel units are pre-loaded to value just greater than that of static friction, this pre-load being additive to break-out force.

In the case of backlash in any part of the circuit it is likely that the stick may look centred; however, what is most important, the control surface may fail to centre. In practice, the effort is directed to have both the stick and the surface centred properly; however, it is the latter which really matters. An elastic control circuit complicates the issue further, particularly if there is a noticeable friction near or at the valve, as no amount of pre-load in the feel unit can take up the stretch held by this friction. This will tend to leave the surface displaced by the amount equalled to the existing amount of stretch, thus destroying surface centring[4].

Gradient of force versus displacement

This can be linear, non-linear or variable depending on the design normally dictated by response characteristics of any particular aircraft in a given axis. In the first case, a simple spring can be employed as a source of feel and, in the second, a combination of springs to give varying force gradient.

In variable force systems governed by q or V law, a feel device would change its characteristics with dynamic pressure.

Ratio of control surface movement to stick displacement

This again can be linear, non-linear and variable. In the linear case the stick position is directly proportional to jack position or surface displacement. In non-linear design, the ratio of the surface control movement to pilot's stick movements is small near the neutral position, changing to high ratio near the limits of travel. In variable arrangements the pilot can choose and alter the gearing himself or it can be altered for him as a function of speed, height and probably g through some automatic arrangements.

Trim quality

The trimming being achieved by the altering of control surface angle and relieving the pilot's load is normally connected through the control feel unit to the circuit and valve. The actuator on the feel unit alters its point of earthing and thus the load on the pilot's stick.

There can, of course, be problems connected with accurate trim, and these can be attributed in a degree to some of the effects previously mentioned. The rate of trim for a given aircraft is normally a matter of compromise as it is generally chosen to suit the high speed or run-away case. The trimmer overruns are associated with the actuator failure to stop immediately upon de-energizing of the trim button. The delays in aircraft response to trimming are brought about primarily by poor surface centring due to effects discussed previously and also due to time constant of the actuator motor.

Range of trim

The requirements state the speed range and the loadings through which it should be possible to reduce pilot's force on all controls to zero. Also some amplifying remarks are added with regard to control forces in dives. The trim range may cover full control range or, for safety considerations in the case of a run-away trim, only part of it, but in the latter case the above requirements would still have to be met.

Rate damping in rapid control movements

Flow rates up to 25 gpm through valves are not uncommon. It can therefore be expected that the valve spools must be subject to changing hydrodynamic forces during movement. These forces, which normally oppose the valve motion and are proportional to the rate of valve displacement, are felt at the stick and they tend to become very noticeable during rapid and short applications and may be well in excess of steady force gradient of the feel unit. The extent of this effect is dependent on the valve characteristics. In some installations it can be pronounced, while in others negligible. However, if the valve at any stage of displacement becomes unstable, a lightening of force gradient can be experienced at the stick, giving the pilot, after moving the stick, a feel of "overbalanced" control (Figure 11).

Control damping on release after displacement (Figure 13)

When the stick is held at some displacement and released, the centring force tends to return it to neutral trim. The resultant motion of the pilot's control will depend on the gradient of the centring force, the extent of displacement and also on the valve characteristics discussed in the preceding paragraph.

In effect, the pilot's force is substituted now by centring feel force which is gradually diminished as the displacement is reduced. If valve rate forces are high one may expect on release a generally sluggish stick move-

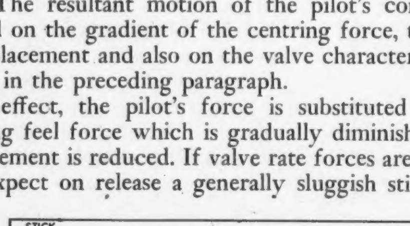


Figure 13
Stick motions on release after displacement

ment, tending to give subsidence, particularly if the feel unit is pre-loaded. If, however, these forces are low, the centring force will snap the control towards the centre and the inertia of the circuit will take it past the neutral position. An oscillation may then result, particularly if friction in the circuit is small and the valve gain over the centre low. The last case was often behind the pilot's complaint of the control not feeling like the one in the "real" aeroplane[4].

Other features

Valve dampers

In some systems, in order to eliminate unwanted valve displacements caused by airframe vibration, control circuit oscillations or oscillatory behaviour of the valve itself, viscous dampers are used at the point where the circuit is coupled to the servo. These dampers will oppose pilot's inputs, particularly in rapid control jerks, and their effect may appear to the pilot as large control circuit inertia[4].

Bob weights

The use of inertia weights in the power control elevator circuit is normally associated with spring feel. The object is to create an addition to stick force proportional to the applied g. In straight flight the weight is balanced by a spring so that its presence should not be noticed. In the past, experience showed that the bob weight could often be "beaten" by rapid control application before the aircraft had time to respond, giving in rapid pull-outs stick force per g which was noticeably less than that obtained under steady conditions with the same bob weight. This led to the present requirement eliminating this possibility.

Most of the discussed characteristics of the feel system components can today be evaluated to a large extent on a specially built control rig which represents mechanical and hydraulic elements of the control system in detail.

In addition, an analog computer can be connected into this rig and simulated aircraft responses presented to the pilot on a cathode ray tube or similar device.

SOME TYPES OF FEEL SYSTEMS AND THEIR MAIN CHARACTERISTICS[5]

Up to now, certain features of the combined elements of the power controls have been broadly covered to show how they affect the ultimate feel, particularly over the centre of the control travel, the accent being laid on break-out and rate damping forces, the backlash, self-centring etc. It is now in order to describe overall characteristics of some of the generally employed feel systems as designed into the aircraft.

Linear Gear

***Pure spring feel* (Figures 14, 15, 16 and 17)**

Because of its simplicity and compatability with the requirements, this type of feel was and is being used often in aileron circuits. It gives constant aileron deflection for a given force, assuming that the power available from the jacks can cope with the hinge moments on the ailerons. This means that in the absence of aeroelastic and Mach number effects the rate of roll for a given force is proportional to speed; furthermore, if the optimum force value is selected for high speed, the low speed response may appear rather heavy. The present trend for the increased stiffness and reduced aspect ratio of supersonic wings, together with enlarged control surfaces necessary for that speed regime, results in high rolling rates at intermediate equivalent airspeeds and generally in rather sensitive lateral feel, even at low speeds. In an effort to cut down this sensitivity, the feel

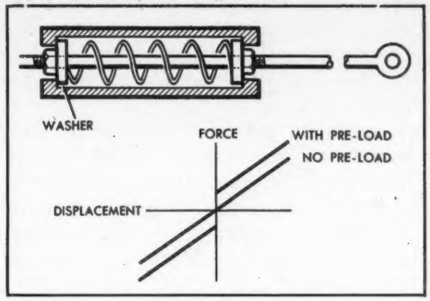


Figure 14
Linear spring and its characteristics

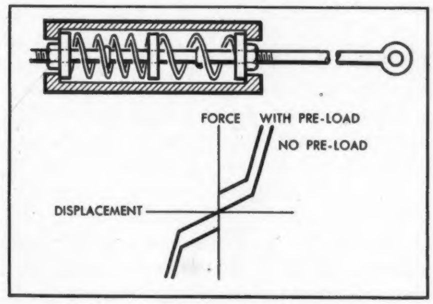


Figure 15
Non-linear spring characteristics

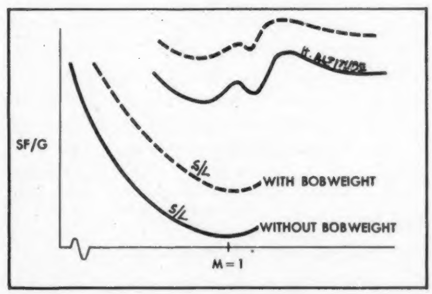


Figure 16
Stick force per g characteristics in spring feel

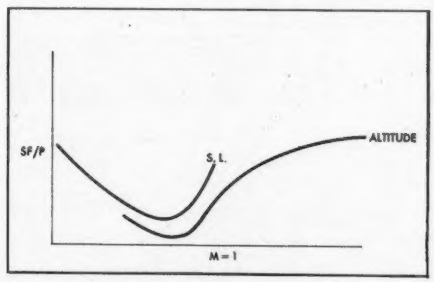


Figure 17
Typical stick force per unit rate of roll in spring feel

may have two force slopes, the initial rather steeper than the final. If, on the other hand, limitations in roll are necessary for some reason, the trend of slopes can be reversed, the force level in this case rising noticeably as the control stops are approached.

In the longitudinal axis, with straight stick to surface gearing, pure spring feel is seldom used because of the difficulty in meeting stick force per g requirements. The stick force per g with pure spring feel is directly proportional to elevator angle per g, and as the latter is known to vary throughout Mach number and height range in the ratio of 20:1 and more, it is obvious that the resultant variation might not be acceptable.

The author has had experience of this feel in an experimental aircraft capable of reaching 630 kts at sea level and 1.25 Mach number in a steep dive. The total force for full elevator deflection was 25 lb up and 15 lb down. At 550 kts below 3,000 ft the stick force, to reach design normal acceleration of 7.5 g, was less than 10 lb (stick force per g 1.5 lb). The great sensitivity at high indicated airspeed was further accentuated by a break-out force which, although low by normal standards (2 lb), introduced easily induced longitudinal oscillations, particularly in the rough air. Supersonically in an altitude dive ¾ of applied g was available against full up elevator (*SF*/g 33.2 lb) giving a ratio in aircraft response to this same command approximately 22:1.

An addition of bob weight to a pure spring feel can produce reasonable force rates for most of the low altitude flight conditions in steady turns or pull outs, but at high altitude and high Mach number they may tend to become excessively high. Also the transient or oscillatory conditions must be closely watched as the first movement of the stick is only held by the spring force which, particularly at low altitude, could be just a small fraction of the total stick force per g.

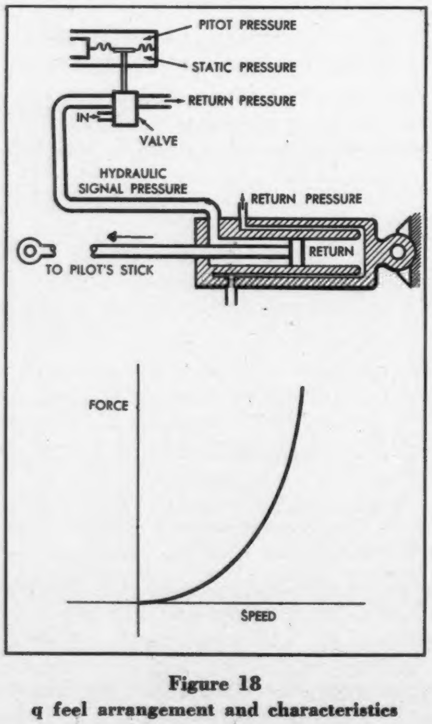


Figure 18
q feel arrangement and characteristics

***q Feel* (Figures 18, 19 and 20)**

Mainly used in the longitudinal axis, this type of feel normally senses dynamic pressure and adjusts stick forces to give constant stick force per g and a force varying as a function of q to hold change of speed.

If used on ailerons, the stick force to obtain a given rate of roll will increase linearly with indicated air speed.

As this feel is based on the dynamic pressure and not the Mach number, the matching of the system to perform correctly at subsonic speeds will result in much larger forces supersonically because, as has been said earlier, approximately twice as large control movements are needed here for the same response. In addition, the compressibility and position error effects at the pressure source will come into the picture and will tend to break down the desirable linearity of feel. To some extent, these complications may be obviated by suitable "scheduling", as, for example, by using a relief valve opening a leak in the pitot lines to the sensing device of q feel to simulate lower dynamic pressure during supersonic flight, or arresting the forces above certain Mach number (q with Mach cut off).

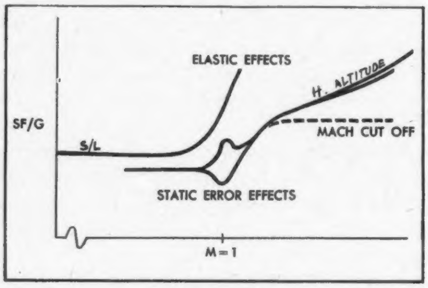


Figure 19
Stick force per g characteristics in q feel

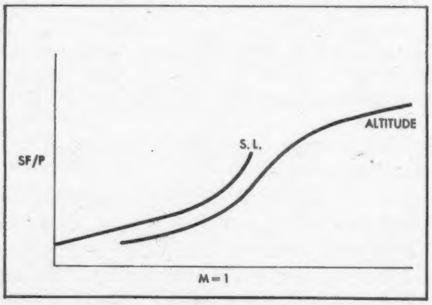


Figure 20
Typical stick force per unit rate of roll in q feel

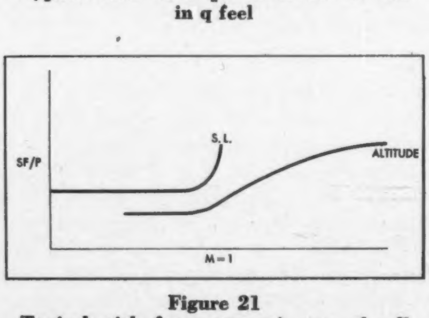


Figure 21
Typical stick force per unit rate of roll in V feel

***V* Feel (Figure 21)**

A type of feel where spring rate varies with V_1. The stick force per g falls off with speed slightly less rapidly than in a pure spring feel. The out of trim forces are normally changing in a linear manner increasing with speed, and the stick force to obtain a given rate of roll is constant with speed.

Similarly to q feel the V feel device senses a modified dynamic pressure and it is likely to be subject to the same shortcomings in the transonic and supersonic flight. To add another, common to both systems, is a possibility of failure of the sensing unit which could suddenly present the pilot with either excessively light or heavy control forces and, in the latter case, possibly insufficient control command through force restriction in approach and landings.

Non-linear gear (Figures 22, 23, 24, 25 and 26)

In the non-linear arrangement the ratio of control surface movement to the movement of the stick is small near the neutral position changing with displacement to high ratio near the limits of travel. In this case (on the elevator) spring feel is often used with either linear or non-linear force gradient versus displacement and sometimes a bob weight. On the ailerons spring feel would normally be employed. A typical example of non-linear gearing is used on the North American F-100C slab tail in conjunction with a non-linear spring[6]. The original F-100A with a linear gear, non-linear spring and a bob weight provided the pilot with over-sensitive control at high speeds and was a source of unfavourable comments by the pilots. To remedy this situation, a non-linear gear was designed and bob weight eliminated.

As can be seen from Figures 22[6] and 23[6], where non-linear curves are superimposed on the original curves the amount of tail plane angle available within one inch forward and back from stick neutral position has been reduced from a total of 7½° to 3° (ratio of 2.5:1) and within two inches of fore and aft movement from neutral, from 16° to 8° (2:1). (In addition, the break-out forces were reduced from 4 lb to 2 lb, approximately 0.1 inch backlash eliminated, and the force gradient increased over the centre in the ratio of approximately 2:1.)

The primary object of this alteration was probably to obtain much smaller variation in stick force per g (and also stick travel per g) throughout the Mach number and height range, and no doubt also to cut down the sensitivity at high indicated air speeds.

In the more commonly known F-86E (Figure 24) the gearing between the stick and directly linked stabilizer is non-linear. In addition, the elevator is non-linearly geared to the tailplane in such a manner that in the high speed or Mach number case (forward stick range) it is virtually fixed and moves as an extension of the stabilizer. In the low speed case, the elevator contribution becomes progressively more pronounced until it becomes dominant near the aft stop.

If the plot of the "equivalent elevator" (Figure 25[7]) were made by the reduction of both elevator and tailplane effectiveness to read as one, the movement of such control versus stick displacement would change very rapidly with the latter.

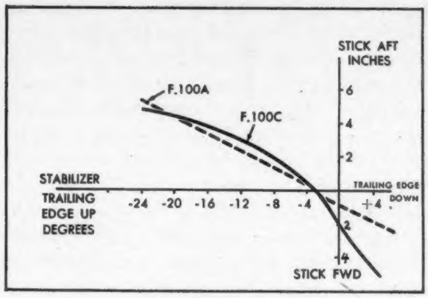


Figure 22
Linear and non-linear relationship of F-100A and F-100C

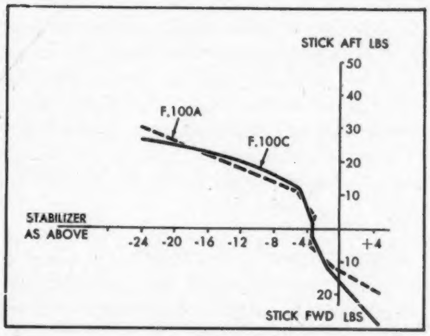


Figure 23
Example of non-linear spring F-100A and F-100C

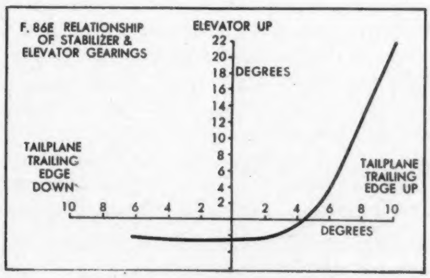


Figure 24
F-86E Non-linear gearing

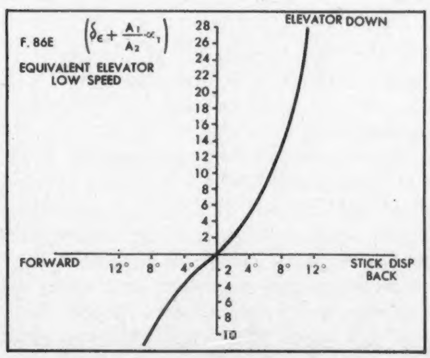


Figure 25
F-86E Non-linear gearing

There are certain disadvantages inherent in the use of non-linear gear. In the longitudinal axis it is of course desirable that the centre of the reduced ratio of control to stick movement occurs at high speed around the trim position. Now if large trim changes are present, say due to CG movement during flight, the trim at high speed at one stage of flight would not correspond to that of the other, thus positioning the control out of the optimum in the non-linear slope and the handling characteristics could change. Normally, however, each non-linear gear is suited to the aeroplane after its characteristics are known and this difficulty could probably be alleviated by suitable choice of gearing over the centre. Another problem arises in lightening of force with increasing g. This one is probably solved with non-linearity in spring rate. A typical example of *SF*/g for this type of gear is given in Figure 26.

On the ailerons it seems that in areas of low control effectiveness (landing case, supersonics or near control reversal due to elasticity) the reduced slope of control surface displacement to stick displacement near the centre would tend to accentuate this lack of effectiveness for small control movements, while full available response would still be obtained with the stick near the lateral stops.

Variable gear (Figures 27, 28 and 29)

In a variable gear control the ratio of the pilot's control movement to surface movement can be altered during flight to fit the response characteristics in a given flight regime. The author has had some experience of this type of system in a power operated transonic delta. In this case the gear was changed on the elevons manually between 1:1 and effective 12:1 ratio. Both the aileron and the elevator sense were altered at the same time and in the same ratio. A simple spring feel was used in both axes and it could be jettisoned to release force level in the manual reversion case. Incidentally, this last feature proved useful during investigation of possibilities of control without any feel. Pilot's stick range of movements was always the same and so were his forces for a given displacement. However, as can be appreciated, the aircraft responses changed directly as the gearing.

In 1:1 gear ratio the aircraft was lively, tending at high indicated airspeeds to become highly oversensitive both in pitch and roll. These characteristics changed gradually as the gear was wound down, giving in 12:1 ratio a sluggish response and heavy feel. The diagram in Figure 27[8] shows how the gear change could be solved mechanically.

During the flight testing of this aircraft it became evident that the method of simultaneous gear change in both axes was not entirely suitable as different ratios were required in roll and pitch for optimum harmony of feel. This necessity was recognized later in the Fairey FD2 where the variable gear has different range of ratios on the elevator (1:1 to 9:1) and aileron (1:1 to 6:1), both being under the control of the pilot separately. This principle of control is applied in the Convair B-58. According to reports of the aeronautical press, the Hustler uses a variable gear system capable of changing ratios from 1:1 up to 25:1, this being varied automatically with airspeed, air density and g loading "without the pilot being aware of change in the stick feel".

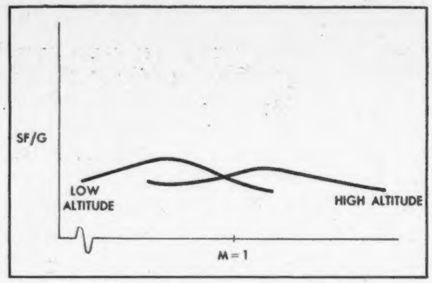


Figure 26
Stick force per g characteristics in non-linear gear

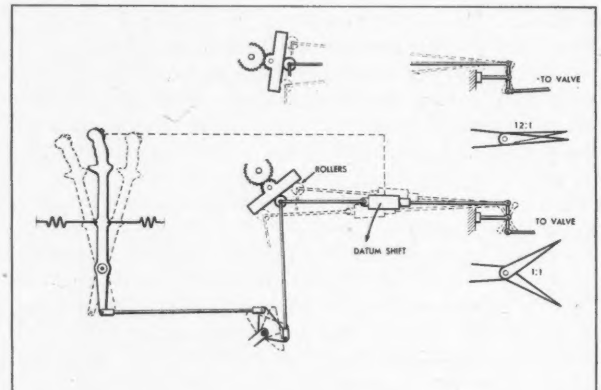


Figure 27
Schematic arrangement of variable gear

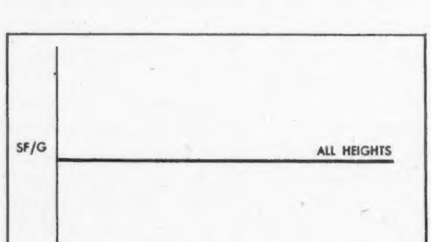


Figure 28
Stick force per g characteristics in variable gear or synthetic feel

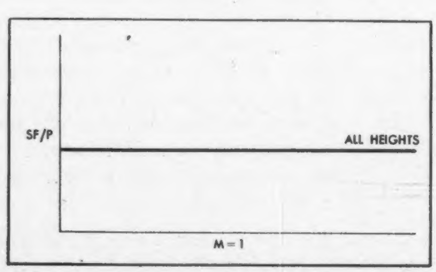


Figure 29
Typical stick force per unit rate of roll in variable or synthetic feel

To give the pilot such "constant feel", as we have seen from previous considerations, cannot be a straightforward matter. Many complicated problems would have to be overcome, one of the most important being that of safeguarding against failure of the variable gear. In such an event the pilot could, for example, be left with only a fraction of normal control surface range to execute the landing. Then there are trimming problems, particularly in rapidly changing height bands and speeds where the datum for each gear and condition would have to be accurately positioned to allow full fore and aft symmetry of available control surface range. There is also a problem of protecting the structure in the event of equipment failure and selecting such scheduling of gear as to enable the aircraft to realize its design envelope at all times.

Synthetic feel (stick steering) (Figures 28, 29 and 30)

This type of feel utilizes an electrical signal from the stick and converts it through the electronic network into any desirable form. A block diagram of a typical arrangement is given in Figure 30 and an explanation to fit this particular and very simplified picture is as follows.

When the pilot exerts force on the stick grip in order to command aircraft response, a contact is closed in the transducer and the stick force converted into a voltage which is fed into the comparator where it is suitably computed and sent to the position servo. The servo is an electro-hydraulic unit which responds to the computed signal. This response is converted into movement of the servo rod which is connected to the power control valve. The valve movement directs hydraulic fluid to the appropriate side of the piston, which in turn moves the control and thus produces a certain aircraft response, for example, an increment of g. This is immediately sensed by the accelerometer which in turn sends its own signal to the comparator. In the comparator the command and the g signal are continuously compared and the excess of the former over the latter, called error signal, produces further servo motion.

When the required amount of g is reached, the pilot will arrest any further build-up of force on the stick grip. The command and the accelerometer signals which

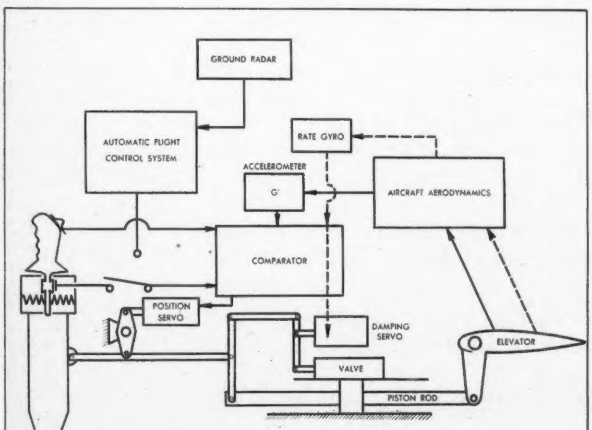


Figure 30
Example of synthetic feel

act in opposition will now be equal, and the error signal will be zero. The travel of the servo will be proportional to the control surface movement, but the movement of the piston rod will cause the valve to recentre and the elevator motion will be arrested at this instant.

As can be seen, the position servo is directly connected to the control column; therefore its movement will displace the pilot's control column in direct proportion to the surface movement. As the response of the system is to all intents and purposes instantaneous, the pilot will have the impression of actually moving the stick whilst it is, in fact, being moved for him by the position servo and rod linkage. In order to reduce the steady g and return to level flight, the pilot will reduce his pull on the stick grip, introducing a reversed signal into the comparator and as the g comes off the process is now reversed.

A similar arrangement can of course be used on the ailerons, the difference being substitution of the accelerometer by the roll rate gyro.

In practice, complicated dynamic studies have to be made of the system to ensure that no undesired oscillations occur in reaching steady state and additional signals, such as pitch rate, may be required to stabilize the system.

As can be appreciated, any form of feel could be designed into this system. Normally, as described above, a constant stick force per g would be the net result in the pitch axis as the output of the transducer is always proportional to the force applied to it, and constant g is applied to the airframe no matter how far the stick moves.

In the lateral axis a constant force for a unit rate of roll might be used. The control movements would, in the case under discussion, be directly proportional to the control surface movement which, as has been mentioned earlier, depends on different flight regimes.

It may also be of interest to add here that within the elements of the system, provision can be made for g restriction to protect the structure and the rate of roll limitation to prevent cross-coupling, which has been a source of difficulty in a number of modern aircraft.

As a by-product of this type of control system, the aircraft which might otherwise have undesirable characteristics can be stabilized by the introduction of another loop outside the transducer loop, as shown by the dotted line in Figure 30.

In this case a rate gyro (sensing changes of rate of pitch in longitudinal oscillations in poorly damped flight regions) could be made to operate a fast response servo to deflect the elevator in a stabilizing sense, without the pilot being aware of the corrections being made.

It can also be anticipated that in the extreme case one might dispense with the connection between the position servo and the control in the cockpit altogether, relying purely on pressure feel without any movement. (Some advantages of this type of feel have been demonstrated in the field of tracking.)

The final advantage lies in the possibility of controlling the aircraft automatically from the ground, the pilot's duty changing into that of monitoring the automatic interception, weapon firing, return to base and approach. Eventually, automatic landing could be made possible.

As in the case of variable gear and others (q and V feel), difficulties with the synthetic feel arise in meeting emergency provisions in the eventuality of the system failure. This, however, lies outside the scope of this paper.

WHAT ABOUT THE FUTURE?

A synthetic approach to feel, dictated by complexity of response met throughout the operational speed and height range of modern aircraft, has commenced a move towards complete severance of direct tie-up between the pilot and the control surface. The control surface deflections and rates in future vehicles which must rely on artificial stability, both static and dynamic, may not bear any relation to the pilot's input at his controls in the cockpit. The friction, backlash and hydrodynamic or other feedbacks will be eliminated and the break-out or centring force adjustable by each pilot to any level which might suit him best. Other forms of pilot's controls may be introduced in departure from conventional stick and rudder. The tendency in engineering design will probably be towards creating readily exchangeable "package" units containing feel, power and electronic elements, which could be tested on suitably designed rigs on the ground prior to embodiment in aircraft. The main problem in this promising picture appears to lie in acceptable levels of safety in the event of failure of the complicated equipment necessary to make this concept a reality. This problem will no doubt also be solved in time by the design refinements and increased reliability of equipment to give the pilot a safe and efficient aeroplane under all design conditions. To what extent, however, the aircraft will lose their individuality of feel, the future only will show.

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(7) Walker, J. G. – *A Note on the Use of Non-Linear Gearing in Artificial Feel for Pitching Control*, MOS/RAE AERO 2464.

(8) Kerr, T. H., and Clark, J. – *Flight Test Measurements at High Mach Number of the Longitudinal Short Period Oscillation of a 45° Swept Tailless Delta Having Taper Ratios of .001, 0.14 and 0.17*, MOS/RAE TM AERO 491.

ROYAL VISIT 1959

H.R.H. The Prince Philip has graciously consented to address engineers and scientists at a luncheon at the Royal York Hotel, Toronto, at noon on Monday, June 29th. Groups participating are:

CANADIAN AERONAUTICAL INSTITUTE
CANADIAN COUNCIL OF PROFESSIONAL ENGINEERS
CANADIAN INSTITUTE OF MINING AND METALLURGY
CHEMICAL INSTITUTE OF CANADA
ENGINEERING INSTITUTE OF CANADA

Applications for tickets should be made immediately to:

Engineers and Scientists Committee
P.O. Box 62,
Postal Station Q,
Toronto 7, Ont.

The ticket allotment will be one to a person and the applicant must indicate his registration with one of the organizations participating. Tickets are non-transferable.

A cheque in the amount of $5.00, payable at par in Toronto, must accompany each individual application. Cheques should be made payable to the Engineers and Scientists Committee.

Distribution of tickets will be made on June 1st taking into consideration

(1) Order of receipt of application
(2) Fair distribution to participating organizations

C.A.I. LOG

SECRETARY'S LETTER

50th ANNIVERSARY CELEBRATIONS

On the following pages you will find a report on the Special Anniversary Meeting held in Montreal to celebrate the 50th Anniversary of Flight in Canada. Further on, under Branches, there is a report on a meeting held by the Halifax-Dartmouth Branch and I wish that the lay-out of the Journal were such that we could give this meeting more prominence; for it was a very worthwhile and successful contribution to the celebration of The Day. The Branch invited the local Branch of the E.I.C. and the Association of Professional Engineers of Nova Scotia to join them, and they put on a Dinner, attended by many notables of the Province and addressed by Mr. Donald Turnbull, son of the late Dr. W. Rupert Turnbull.

At the other side of the country, the Vancouver Branch participated in a Dinner staged by the "Golden Flight Committee". I believe that their participation was significant, though it was not an affair inaugurated by the C.A.I. Similarly in Winnipeg there was a Dinner in which the C.A.I. participated, though not as the moving spirits.

Professor T. R. Loudon addressed a 50th Anniversary Dinner which the Toronto Branch held on the 18th February, considerately avoiding a clash with the Institute's Meeting planned for the 23rd. (But Fate was not so considerate to them, the weather and the Government of Canada conspiring to effect a substantial reduction in the attendance from Toronto at the Meeting in Montreal.)

The Ottawa Branch held a meeting on the 11th March with special emphasis on the Anniversary theme. Ladies were invited and, after a buffet supper, Mr. J. H. Parkin presented a historical paper.

So, all in all, the Institute paid due tribute to this noteworthy occasion.

NATIONAL COORDINATING COUNCIL

With the passing of the 23rd February, the major work of the National Coordinating Council for the Golden Anniversary of Flight in Canada came to an end and, though the Council is still in being, its full-time Coordinator, W/C H. Pearce, left us to take up an appointment in the automobile business that has been waiting for him for several months. We miss his cheery presence around the office.

THE NEED FOR MORE BRANCHES

For some time there have been small groups of members in two or three "centres of aeronautical activity" which have never quite attained sufficient size to become Branches. The places I have in mind are Quebec City, Amherst/Moncton and Trenton. I should like to suggest that the members in each of these groups should put their heads together to consider how the local membership can be increased to Branch proportions by the fall. We will give them all the help we can from Headquarters but primarily it is up to the local members to persuade their colleagues of the advantages of membership, particularly when there are enough of them to organize a programme of regular meetings throughout the winter season.

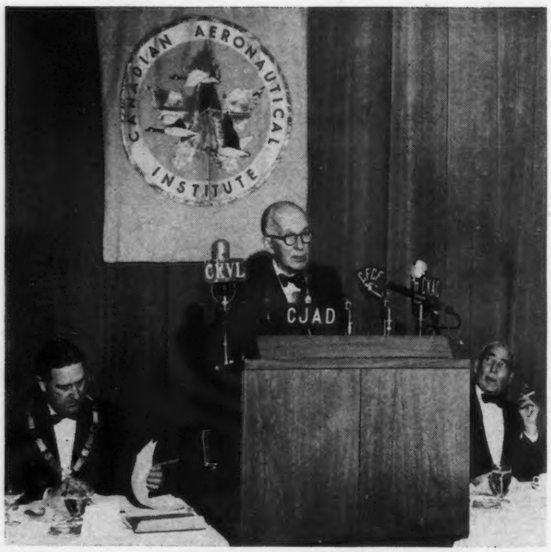
ROYAL VISIT

In conclusion, I should like to draw attention to the notice appearing on the opposite page, announcing the Luncheon to His Royal Highness the Prince Philip, which will be held in Toronto in June. At one time we tried to arrange for our Patron to take part in some purely aeronautical event associated with the 50th Anniversary of Flight in Canada; but the programme of the Royal Tour was too crowded. We and the other four national organizations were in fact very fortunate in having the time allotted to us for this one opportunity to entertain His Royal Highness on behalf of all the scientists and engineers in Canada. I hope that the C.A.I. will be well represented.

SPECIAL ANNIVERSARY MEETING

Two important national events were staged on the 23rd February, 1959, to mark the Fiftieth Anniversary of Flight in Canada. The first took place at Baddeck, N.S., in the morning and the second in Montreal, some 650 miles away, in the evening; thanks to fifty years of progress, in the form of an RCAF Comet and a chartered TCA Viscount, many people were able to attend both ceremonies without much difficulty.

At Baddeck, the RCAF flew a full scale model of the Silver Dart, reenacting the flight which Mr. J. A. D. McCurdy made in 1909. The wind, in 1959, was gusting up to 35 kts and gave W/C P. A. Hartman an uncomfortably kite-like ride, which ended rather abruptly on the rudder and port wing-tip; but the flight was in itself a historic event and a very telling reminder of the achievement which it commemorated.



His Excellency, The Rt. Hon. Vincent Massey, delivering his address

In the meantime the Institute was holding a two-day Meeting in The Queen Elizabeth, Montreal. Technical sessions were held in the morning and afternoon and, in the evening, a Dinner at which His Excellency, the Governor-General of Canada, was the Principal Speaker. On the following day, the 24th February, there were two more technical sessions, and the Institute's Astronautics and Propulsion Sections joined forces to hold a luncheon, which included a technical address.

In contrast to the Dinner, the technical work of the Meeting was directed towards the future of flight, both in the atmosphere and in space, and some first rate papers were presented. The technical sessions were well attended, total registration being 380. The sessions and the luncheon will be reported upon later.

Unfortunately the proceedings were marred by the untimely Government decision to cancel the Arrow programme. This was announced on the preceding Friday, the 20th February, and it cast a baleful shadow over the celebrations. Combined with bad flying weather in southern Ontario, it reduced the attendance from Toronto to a mere handful.

On the credit side, however, no report of this Meeting would be complete without recording the fact that the Institute shared the Convention Floor of the hotel with a Hairdressers' Convention. The distinguished speakers met some stiff competition from the many-splendored coiffures constantly gliding by the registration desk.

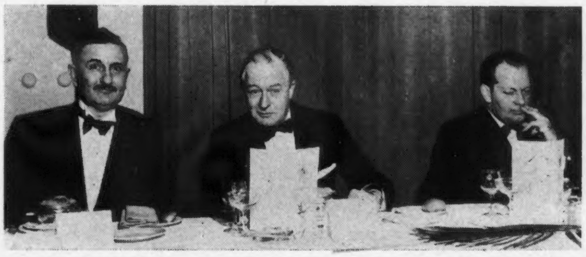
THE DINNER

The Dinner in le Grand Salon was arranged and run by the Institute, acting as host and spokesman for many branches of Canadian aviation. The President of the Institute was in the chair, supported at the Head Table by the senior officers and executives of all the organizations forming the National Coordinating Council for the Golden Anniversary of Flight in Canada. The souvenir menu card, bearing the crests of the Institute and of the National Coordinating Council, expressed the spirit of the event. As previously mentioned, His Excellency the Right Honourable Vincent Massey, Governor-General of Canada, honoured the occasion with his presence. The Honourable J. A. D. McCurdy was there and, at the Ladies Tables in front, the Aerial Experiment Association was also represented by Mrs. F. W. Baldwin and two of Dr. Alexander Graham Bell's granddaughters, Mrs. J. M. Jones and Mrs. Leonard Muller. In addition, the guests included Mr. William Littlewood, President of the Institute of the Aeronautical Sciences, and, although Sir Arnold Hall, President of the Royal Aeronautical Society, was unable to come, he was represented by Sir George Gardner, Director, Royal Aircraft Establishment, Farnborough. Another eminent visitor was Dr. H. L. Dryden, Deputy Administrator, National Aeronautics and Space Administration. The total attendance, though sadly affected by last minute cancellations from Toronto, was 711.

The President introduced the Head Table guests as the meal drew to its close and, with them, he included Mrs. Baldwin, Mrs. McCurdy, Mrs. Jones and Mrs. Muller. A burst of applause greeted the introduction of Mr. McCurdy and each of these ladies, despite the President's request that applause should be held until he had finished. The President then read a message which he had sent to His Royal Highness, the Prince Philip, as follows:

"I am sure that Your Royal Highness, as our most distinguished Patron, will be interested in the Special Meeting to be held by the Canadian Aeronautical Institute in Montreal next Monday and Tuesday, to mark the Fiftieth Anniversary of Powered Flight in Canada. Eminent British and American Scientists will participate in an unusually interesting programme to discuss future aeronautical and astronautical developments. On

THE HEAD TABLE



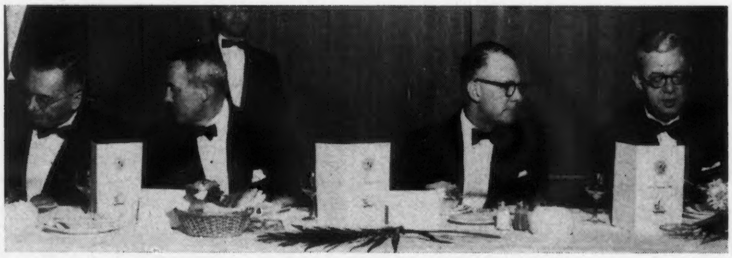
(left to right) Mr. H. C. Luttman (Secretary, C.A.I.), Mr. H. P. Illsley (President, Air Cadet League of Canada), and Mr. Lionel Massey (Secretary to the Governor-General)

Mr. J. R. Baldwin (Deputy Minister of Transport), Mr. F. T. Wood (Vice-President, Air Industries & Transport Association), and Mr. William Littlewood (President, Institute of the Aeronautical Sciences)

Air Marshal H. L. Campbell (Chief of the Air Staff), Dr. E. W. R. Steacie (President, National Research Council), and Air Marshal W. A. Curtis (President, Royal Canadian Air Force Association)

Air Marshal W. A. Curtis, His Excellency the Governor-General, and Dr. G. N. Patterson

The Hon. J. A. D. McCurdy and The Hon. Sarto Fournier (Mayor of Montreal)



Dr. H. L. Dryden (Deputy Administrator, National Aeronautics and Space Administration), Dr. A. H. Zimmerman (Chairman, Defence Research Board), Vice-Admiral H. G. DeWolf (Chief of the Naval Staff), and Sir George Gardner (Director, Royal Aircraft Establishment)

Mr. G. J. Stringer (President, National Co-ordinating Council for the Golden Anniversary of Flight in Canada) and Mr. S. F. D. Sampson (President, Canadian Owners and Pilots Association)

Mr. Peter Fisher (President, Royal Canadian Flying Clubs Association), Mr. Roy Kervin (Director, Canadian Region, Aviation Writers Association), and Wing Commander Harold Pearce (Coordinator, National Coordinating Council for the Golden Anniversary of Flight in Canada)

The Hon. J. A. D. McCurdy

Air Marshal W. A. Curtis moving the vote of thanks

Monday, His Excellency The Governor-General will address a Banquet attended by representatives of all branches of Canadian aviation and of Dr. Alexander Graham Bell's Aerial Experiment Association which built the Silver Dart aeroplane. The latter will include The Honourable J. A. D. McCurdy who flew the Silver Dart at Baddeck, N.S., on the 23rd February, 1909, thereby becoming the first British Subject to fly in the British Empire.

"The Council and members of the Institute and our guests at the Banquet will wish me to send greetings to Your Royal Highness on this historic occasion.

G. N. Patterson, President"

He then read the reply, which he had just received,

"I am very pleased to hear that you are arranging a Special Meeting to commemorate the 50th Anniversary of Powered Flight in Canada. I send you my best wishes for the success of the occasion. No other field of human invention has progressed so rapidly as aviation and the pioneers must be very proud of the way their early efforts have been rewarded. It would be difficult to exaggerate the importance of aviation to Canada's present and future and I commend the efforts of the Canadian Aeronautical Institute to foster and encourage all aspects of flying.

Philip"

This message from the Institute's Patron was warmly welcomed. The President went on to read three more congratulatory messages; from Dr. A. M. Ballantyne, Secretary, Royal Aeronautical Society,

Mrs. Joseph M. Jones (l) and Mrs. Leonard Muller, granddaughters of Dr. Alexander Graham Bell, with Mr. Guy Robillard, a member of the Governor-General's party

"What was started fifty years ago has been carried on with outstanding success. Best wishes for a fitting celebration."

from Mr. George Drew, Canadian High Commissioner in London,

"Please convey my warmest personal good wishes to the Honourable J. A. D. McCurdy and all those attending this historic Fiftieth Anniversary Dinner. May I join you all in congratulations to the pilot of the first aircraft flown in the British Empire."

and from the Secretary General, Air League of the British Empire,

"The President, Council and members of the Air League offer their sincere congratulations of the Jubilee Anniversary of the flight of the Silver Dart, piloted by J. A. D. McCurdy, at Baddeck on the 23rd February, 1909.

"The thoughts of all of us who have been privileged to fly in Canada, or with Canadian airmen, or who have knowledge of the great and continued achievements of all branches of Canadian aviation, will be with you gathered at Baddeck and at the Queen Elizabeth Hotel in Montreal on the 23rd February, 1959."

Before introducing the Principal Speaker the President said, in part, "Fifty years ago today, on February 23rd, 1909, John McCurdy flew the Silver Dart from the ice of Baddeck Bay, Bras D'Or Lakes, in Cape Breton Island. He flew for over half a mile at a height of some 60 ft and a speed of about 40 mph and then landed successfully. This was the first flight of a powered heavier-than-air machine in Canada. This Special Anniversary Dinner is being held to commemorate that significant event in Canadian history.

"The Silver Dart was one of a series of powered aircraft developed at Hammondsport, N.Y., by the Aerial Experiment Association, a group of American and Canadian aeronautical pioneers headed by the famous scientist, Dr. Alexander Graham Bell. During the early operation of this Association, "Casey" Baldwin flew the Red Wing over a lake in New York state on March 12, 1908, and became the first Canadian to fly in a powered aircraft. You will hear more about these and other early pioneers later this evening.

"In order to avoid conflicts between the programs planned by various organizations in honour of the first powered flight in Canada, a National Coordinating Council was formed at a meeting called by the Air Industries and Transport Association. Many of our head table guests are representatives of the member organizations. The National Coordinating Council encouraged the formation of local planning committees and a number of functions are organized for this year at various centres across Canada. On this very special day two national events were approved by the Council. This morning the Royal Canadian Air Force reenacted at Baddeck the famous flight of fifty years ago

using a full-scale model of the Silver Dart. It is the pleasure of the Canadian Aeronautical Institute to sponsor the second national event – this Anniversary Dinner and the associated technical sessions.

"Our sincere thanks are due to the Royal Canadian Air Force for cooperating in the coordination of the ceremony at Baddeck with this Dinner and for providing an airlift for some of our guests so that they could attend both functions. We appreciate the considerable assistance provided by W/C Pearce, full-time Coordinator for the Council, and the excellent arrangements made by the Montreal Branch of the CAI under the able chairmanship of W/C Thompson.

"I should like to take this opportunity to thank the speakers taking part in our technical sessions for their valuable contributions. In particular I should like to mention the excellent talks given today by our distinguished visitors Sir George Gardner, this morning, and Dr. H. L. Dryden, this afternoon. Our thanks are due also to the Session Chairmen: Mr. R. D. Richmond, Dr. J. J. Green, Dr. H. S. Ribner and Mr. R. H. Guthrie.

"Our gratitude for the past would be of little value if it did not provide encouragement for the future. Present progress is typified by a comparison between the Silver Dart and aircraft recently produced in Canada. The Silver Dart had a gross takeoff weight of some 750 lb and a speed of about 40 mph. The Canadair Argus, the largest aircraft ever constructed in Canada, has a gross takeoff weight of the order of 150,000 lb. The Avro Arrow, the fastest aircraft ever built in Canada, has a speed in excess of twice the speed of sound. The DeHavilland Caribou has demonstrated outstanding short takeoff and landing characteristics. Canada is justly proud of these and many other aeronautical achievements during the past fifty years. In reply to those who doubt that Canada can make a worthwhile contribution to aeronautics and astronautics in the next fifty years, we point with confidence to these achievements of the past."

On concluding his remarks, the President expressed his pleasure and privilege to introduce the most distinguished Guest of Honour and Principal Speaker, the Right Honourable Vincent Massey.

His Excellency's address is given in full on pages 126 to 129. None who heard it will ever forget it; it was indeed, as the President said, "a gracious tribute to Canadian aviation over the past fifty years and an inspiration for the future". All those present, from all fields of Canadian aviation, recognized His Excellency's words as a fitting epilogue to fifty years of Canadian aeronautical endeavour, in war and peace, in research, engineering, manufacture and operation.

Mr. McCurdy had agreed to say "a few words" after the Governor-General's address. In spite of a long and tiring day, which had begun at Baddeck in the morning, he was in wonderful form and he gave a vivid account of the morning's events, which he had evidently thoroughly enjoyed. He spoke glowingly of all concerned with the building of the Silver Dart model and particularly of W/C. Hartman for his skillful flying under very difficult conditions. He also thanked the good people of Baddeck for all they had done to make this so memorable a day.

The President called on Air Marshal W. A. Curtis to move a vote of thanks and, in so doing, the Air Marshal announced that, at Baddeck in the morning, Air Marshal H. L. Campbell, Chief of the Air Staff, had bestowed upon Mr. McCurdy the rank of Honorary Air Commodore. This timely and appropriate honour received enthusiastic applause. Air Marshal Curtis concluded by reminding his listeners that Mr. McCurdy's early attempts to interest the Army in the Silver Dart had failed, because it was considered that the aeroplane had no military value. The echoes over fifty years seemed to be lost on many of his hearers.

At the close of the proceedings, all those present rose and stood in their places as His Excellency and the President left the room. Thus ended the national celebration of the Golden Anniversary of Flight in Canada.

Before leaving the hotel with his party, His Excellency received a small group of senior executives of Sustaining Member companies.

Atmospheric Flight Session: (l to r) Mr. R. J. Templin, Mr. R. D. Richmond (Chairman), and Sir George Gardner

TECHNICAL SESSIONS

Members of the Montreal Branch have submitted the following reports on the technical sessions held during the two days of the Meeting.

Morning Session, February 23rd

Atmospheric Flight

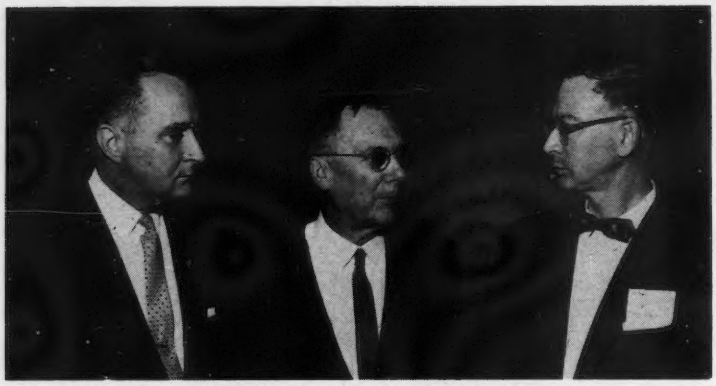
Reported by G. T. McLean

The first papers presented to the Special Anniversary Meeting dealt, appropriately enough, with past, present and future considerations of atmospheric flight.

Sir George Gardner of the Royal Aircraft Establishment and Mr. R. J. Templin of the National Research Council, in their presentations to a capacity audience, ranged from a specification for a military aircraft of 1908, through today's passenger and freight problems, to the supersonic airliner of tomorrow and with considerable information and thought on VTOL and STOL aircraft.

It is not the intention of this report to detail the contents of the two excellent papers presented by these highly qualified men. Suffice to say that the interest of the audience was obviously held during the lectures and, as further evidenced, by the discussion periods that followed.

It was obvious, from the questions directed from the floor, that engineering aspects of VTOL aircraft were uppermost in the minds of a good percentage of the audience. Among those heard from, pertaining to this type of aircraft, were Messrs. J. L. Orr of DRB, A. D. Wood of NAE, and A/V/M A. Ferrier. Line of questioning centred on clarification of graphical illustrations and a question of speed characteristics. Mr. E. L. Smith of Canadian Pratt & Whitney queried Mr. Templin on the method of acquiring large



Space Flight Session: (l to r) Mr. G. D. Watson, Dr. H. L. Dryden and Dr. H. S. Ribner (Chairman)

amounts of lift force without the expenditure of a large amount of energy.

All in all, the floor discussions were lively and informative, although it is not possible here to list them all. As a finale to the morning's business, Mr. A. G. Sims of Canadair presented a remarkably well preserved film depicting a flight in 1919 in which Maj. Barker, V.C., took the Prince of Wales for a flight over London.

Afternoon Session, February 23rd

Space Flight

Reported by Dr. E. Bendor

The fact that a whole afternoon session was given over to the subject of Space Flight (and the following session to Satellites) has an obvious significance on this 50th anniversary of powered flight in Canada. Nor was this significance likely to be overlooked by the meeting. It must have seemed ironical that the absence of Mr. J. C. Floyd of Avro Aircraft Ltd. was, in a sense, due to the very developments over the perusal of which he was to have presided.

Whilst Mr. Floyd was presumably attending to much publicized (and lamented) events in Toronto, his place as Chairman was ably filled by Dr. H. S. Ribner, of the Institute of Aerophysics, University of Toronto. Dr. Ribner is the Chairman of the Institute's Astronautics Section. His task on this occasion was to introduce first, Dr. H. L. Dryden of the National Aeronautics and Space Administration and, later, Mr. G. D. Watson of the Defence Research Board.

The Chairman launched the session with a brief introduction of Dr. Dryden. The large audience seemed to indicate that, in fact, Dr. Dryden needed little introduction. It is sufficient to record here that he was for almost eleven years head of NACA and more recently Deputy Administrator of NASA, an organization set up to supersede NACA and to extend its activities into the fields of rocketry and space flight.

In his opening remarks, Dr. Dryden conveyed to us the greetings of NASA and of the Institute of the Aeronautical Sciences. Although his lecture was entitled "Recent Trends in Aeronautics and Space Research in the United States", it was his intention also to extrapolate these trends into the "near" future. He did not intend, as he put it, "to compete with the writers of science fiction". Indeed, in volume alone, this would have been a difficult task. Nor did Dr. Dryden feel impelled to undertake it, and put his point forcibly by quoting Wilbur Wright's dictum that "it is not necessary to look too far into the future; we see enough already to be certain that it will be magnificent".

Dr. Dryden's lecture was concerned therefore with the major developments in research during the period of time commencing toward the end of World War II and ending say ten or fifteen years from the present. He indicated how the arrival of jet propulsion was accompanied by simultaneous advances in structures, aerodynamics and aeroelastics, leading to the very advanced turbine power aircraft of the present day. The great contribution of the various NACA establishments to our understanding of the phenomena of supersonic flight, particularly in aerodynamics, is appreciated by all concerned. It was interesting to hear from Dr. Dryden that investigations into the possibilities of supersonic flight were initiated by NACA as early as 1942.

As regards the more immediate past and the present, the speaker outlined some of the main areas on which interest was focused – hypersonic aerodynamics, reentry of nose cones, development of materials for high temperatures etc. Some of the experimental facilities available for these investigations, for example, an electric arc powered air-jet capable of reaching temperatures of 12,000°F, were illustrated with slides. The existence of a series of rocket-powered hypersonic research aircraft is well known. Dr. Dryden mentioned that the latest of these, the X-15, could be operated at altitudes where aerodynamic forces become negligible, and at speeds such that surface temperatures of 1200°F would be reached. Apart from more technical information, something would be learned about the ability of pilots to control this vehicle under conditions of weightlessness. A further manned research vehicle is now under development. This latest addition to the NASA family is to be a long range hypersonic boost-glide vehicle, capable of attaining satellite velocity. One may presume that the speaker was referring to the "Dyna-Soar" project, which has received some publicity in the aeronautical press.

Under the heading of "Research on the Problems of Space Flight", Dr. Dryden traced the participation of NACA back to 1952. The intervening years have witnessed many significant advances. The speaker told us something of the experimental apparatus now in use, for example, low density hypersonic and helium wind tunnels. One of the illustrations was of a gas-gun operated ballistic range, in which velocities of 15,000 ft/sec could be imparted to models. NASA is also deeply involved in the propulsion field. It is interesting to note that subjects, such as aerodynamics, ballistics and propulsion, which have until recently been regarded as separate fields of engineering, have now tended to merge. Although perhaps most obvious in space technology, this blurring of the boundaries is also noticeable at the other end of the speed scale. Developments, such as deflected slipstreams and jet flaps for VTOL and STOL aircraft, indicate how the traditional applications of airframes and powerplants can be used and sometimes even reversed.

In the course of some remarks on the exploration of space, Dr. Dryden pointed out that the function of NASA was not confined to basic and applied research, but extended also to the development and operation of space vehicles. Whilst satellite launchings to date have been accomplished with existing military engines (excepting Vanguard), two very significant programmes have been initiated. Firstly, several engines of the type now available would be "clustered" to provide an initial thrust in excess of 1 million pounds. Secondly, new boosters under development would yield this order of power in one chamber, and subsequent clustering of the latter would produce launch thrusts of up to 6 million pounds. It is hardly necessary to point out that the potentialities opened up by these developments would include interplanetary missions. As Dr. Dryden pointed out, the payload carried by a

space vehicle is a direct function of the booster thrust available. A mature consideration of this fact would have done much to resolve the arguments which arose as a result of the Russian achievements during the past 18 months.

Toward the end of his lecture, Dr. Dryden came to the subject which must surely hold the greatest interest of all. What is to be the role of the species of 'Homo Sapiens' in the exploration of space? Project Mercury was the name so aptly chosen for the US manned satellite programme. The launching of man into orbit and his safe recovery would be preceded by comprehensive tests, first with instrumentation only, and then with animals, before the great step is attempted. An interesting illustration showed how the selected individual would be incarcerated in the space capsule, safely, if somewhat uncomfortably, supported in a reclining position. Much work remains to be done in the field of human engineering, so popular nowadays with social and industrial psychologists, albeit with somewhat different aims in view.

The great interest which Dr. Dryden's lecture had provoked became obvious when Dr. Ribner threw the meeting open to questions and discussion. Of particular interest to Canadians was the question of whether it would be necessary to introduce manned vehicles into orbit by way of the earth's magnetic poles, so as to minimize the hazard of radiation. Replying to a question to this effect, Dr. Dryden seemed to think that it would not be necessary to launch in the vicinity of the poles, provided that the altitudes of most intense radiation were traversed near the earth's magnetic axis. Dr. Patterson of the University of Toronto, President of the Institute, asked whether the effects of small aerodynamic retarding forces were being considered in the planning of satellite orbits. The mechanics of rarefied gases is one of Dr. Patterson's special interests. The lecturer replied that gas densities at satellite altitudes were in fact much greater than had originally been estimated, and that their effect was receiving consideration. One of the illustrations which Dr. Dryden had shown was of a light inflatable sphere of 100 ft diameter which would be used to investigate residual drag.

Two of the questions directed at Dr. Dryden were concerned with nuclear, ionic and photonic propulsion systems, subjects to which the speaker had made some reference in his lecture. In reply to a question from Dr. Ribner, he said that ionic propulsion systems might be of some value where interplanetary trajectories demanded the application of small thrusts for long periods of time. At its present stage of development, an ionic propulsion system might yield about 10 lb thrust for a powerplant weight of 100,000 lb, with a fuel consumption about 1% of that usual in current chemical engine practice. These novel propulsion devices are in such an early stage of development, however, that the above figures might be in error by a factor of 10 or more. Dr. Dryden thought that nuclear propulsion would find an application only where very large payloads and long ranges were required; because of their high weight, their more general employment might be difficult. One might conclude from the lecturer's remarks on these subjects that, for escape from the earth's gravitational field, we would have to rely on large chemical fuel boosters, at least in the near future.

When Dr. Ribner closed the first part of the afternoon session, it was clear that the audience appreciated the fact that they had for once heard prophecies from one who not only made them in moderation but was instrumental in bringing them about.

When the session continued after a short interval, Dr. Ribner introduced Mr. G. D. Watson, of the Defence Research Board, who lectured on "The Exploration of Space". Mr. Watson had pursued his career mostly in the service of Canadian Government Research Establishments, and it was reassuring to hear that the problems of space technology were receiving some attention there.

Mr. Watson opened with a discussion of the space environment. Since space flight would for many years be confined to the solar system, the success of space missions must depend on our understanding of the nature of the matter and radiation associated with the sun. Most important are the physical phenomena in the vicinity of the planets and, in particular, the environment of the earth itself. The speaker singled out the "Van Allen Radiation Belt" for special mention. This region of intense radiation, which surrounds the earth to a depth of some 20,000 miles, appears to have cavities in the vicinity of the earth's magnetic axis.

On the subject of space flight mechanics, Mr. Watson thought that a perigee of at least 200 miles is essential if the life of an earth satellite is not to be drastically curtailed by atmospheric drag. Some typical space trajectories were illustrated, showing the effect of injection velocity, apogee height etc. From an illustration of the path followed by the Russian space probe Lunic, it appeared that the vehicle passed in front of the moon when taking up its new career as an artificial planet. It was somewhat startling to hear that if man were to make a round trip to Mars and back he would be marooned in the orbit of that planet for 1½ years before a suitable opportunity for the return to earth would present itself. Will there be another Daniel Defoe to spin a yarn destined to delight future generations?

What would be the reaction of the human organism when removed from the surroundings to which it has so laboriously adapted itself, spawned by a million lesser species? Here indeed is a question which can hardly be hidden under the mantle of science, a question

Satellites Session: (l to r) Dr. P. M. Millman, Dr. J. J. Green (Chairman), and Mr. D. A. Young

which touches the roots of man's psychological and moral sensibilities. We may well wonder, with Mr. Watson, whether mutations might not take place when humans are removed from the shelter of the earth's atmosphere without adequate protection. When mention is made of adapting man himself to the conditions which he will encounter in space, we are dangerously close to a domain so prophetically analyzed by Messrs. Huxley and Orwell, a realm of philosophy scarcely inhabited by science, let alone ruled by it.

Retiring from the field of controversy, the speaker gave us an account of progress made in Canada during the last 2 years. The fact that a great deal of the Canadian effort in connection with the International Geophysical Year was centred at Fort Churchill is common knowledge. Investigations of the auroral regions and infra-red radiation were carried out and animals were carried in some of the rockets fired. Experiments were also conducted by DRTE and the DRB medical laboratories. A T-33 aircraft was flown at zero acceleration for over half a minute to investigate the condition of weightlessness which Mr. Watson thought might lead to psychological difficulties.

The speaker justified the study of space technology (if such a justification was necessary) by pointing to such applications as weather and astronomical observation, communication using satellites moving in 24 hour orbits etc. Mr. Watson stressed the importance of research in general. The scale of these activities is today so all embracing as to include almost the whole spectrum of basic science and technology. Apart from the advances in communications and meteorology which would be among the by-products of space research, forward strides may be expected in geology and transportation would inevitably reap a rich profit from the techniques now only in their infancy. The problem of navigation in the absence of a magnetic datum is of particular interest in this country.

In Mr. Watson's opinion, and one cannot help but agree with him here, many of the techniques currently in use are marginal. A plea for inventiveness and new ideas must surely be endorsed by all who have learned the lesson which the history of science has to teach. Dr. Dryden had previously shown how even in the recent past we are indebted for vast progress to what he called "step-like jumps" in our ideas, albeit supported by a continuous refinement in established techniques. When science becomes smothered by technology, when the fundamental is drowned in the applied, then surely progress can only last until its inheritance is consumed.

It is to be hoped that Canada will play its part in the conquest of man's extending horizons. The fact that on this 50th anniversary of powered flight our thoughts are so much directed to the future, rather than to the past, must surely bespeak an ever accelerating progress which this Institute is committed to sustain.

After a further brief period for questions and discussion the session closed.

Morning Session, February 24th

Satellites

Reported by Dr. H. J. Luckert

The morning session was chaired by Dr. J. J. Green, Canadian Joint Staff, Washington. Dr. Green opened the session on satellites by pointing to the tremendous achievement in aeronautics during the past 50 years and raising the question, what might the situation be in about 50 years from now when the anniversary of the first man-made satellites would occur? He mentioned that six U.S. and three Russian satellites have been put in orbit, together with one artificial planet sent aloft by Russia.

The first lecture of this session was presented by Mr. D. A. Young, Chief of the Space Technology Branch, Institute of Defence Analysis, affiliated ARPA, USA, whose paper was entitled "Satellites and Space Vehicles".

Mr. Young's lecture was concerned with the military aspects of space, the interest in space being assumed for a distance of two moon radii from the earth, and he described the anticipated military needs for satellites and space ships. In particular, it would be important to develop and operate space weapon systems to detect, identify and destroy attacking vehicles. There are various uses to which satellites could be put, e.g. reconnaissance satellites, orbital weapons for surface bombing, communication satellites, navigational aids, military space force (manned interceptors), space platforms, lunar and interplanetary operations. These possibilities were discussed in detail and Mr. Young also stressed the importance of eliminating useless satellites so that space did not become cluttered with "garbage".

During the discussion period a number of questions were asked. The first question was concerned with the use of manned aircraft with respect to the space program. The lecturer gave his views by saying that anything which was a deterrent to war would always be beneficial. Other topics were the possibility of recovering expensive first stage rockets, the use of solid propellant motors and methods for detecting flaws in the propellant, the relative effectiveness of ICBM vehicles versus "stored" space vehicles, and the vulnerability of launch sites. A quite natural question was why Russian vehicles were much heavier and larger than U.S. vehicles though performing a similar operation. The lecturer stated that the accent of the American approach was on complex and sophisticated guidance and control systems in order to fulfil the purpose with a minimum of weight and thrust. The USSR, on the other hand, had favoured simplicity in the missile and consequently had to obtain the objective by higher overall weight and thrust.

The second paper of this session, entitled "The Contents of Space near the Earth", was read by Dr. P. M. Millman, Head, Upper Atmosphere Research, of the National Research Council. In his very clear and interesting lecture, Dr. Millman stated that in any advanced planning for the launching of a manned space vehicle it is of vital importance to know something of the general physical conditions which are met within space. The subject of the lecture was restricted to the examination of the nature of space in the neighbourhood of the earth, that is the so-called "empty" space along the path of the earth, at the earth's mean distance (one astronomical unit) from the sun.

The contents of this space which is, as the lecture showed, not so "empty" can be divided into three broad categories:

(1) solid particles, large compared with atomic and molecular dimensions,
(2) atomic and molecular particles, and
(3) electromagnetic radiation.

In order to obtain a reasonable comparison, the information which we obtain from various sources about these very diverse phenomena may best be related in terms of mass per unit volume, energy per unit volume, also energy flux across a unit area, and the energy of impact with a single particle.

Dr. Millman discussed first the large particle which can be divided into three groups:

(a) Meteorites, moving in low eccentricity orbits around the sun, with a mean mass of the order of 100 kg per meteorite.
(b) Meteors, ranging in size from a weight of 10 kg to one tenth milligram (mean: about 1 milligram), and moving generally in highly elliptical orbits.
(c) Interplanetary dust, with a representative weight of 10^{-8} gram per particle.

To the next group, the small particles, belong cosmic rays, consisting of very high energy fast moving atomic particles, such as protons, α particles etc. There are also electrons and electron streams.

In the last group, radiation, we have solar and stellar radiation, of which the former is predominant and includes wavelengths ranging from γ-rays to radio waves.

For all these categories, size (particle mass, particle diameter), volume containing one particle impact energy were given and combined in a table showing the representative values for comparison; likewise the solar energy flux at the earth's mean distance from the sun was shown for the whole spectrum.

A large number of slides gave a particularly interesting illustration to the lecture. Also the probability was discussed of colliding with larger particles, in terms of flight time for particle impact; for example a hit of a meteorite would occur once in three million years of flight.

The two interesting papers of this session, in combination with the skillful chairmanship of Dr. Green, found a very attentive audience in a well attended meeting.

Afternoon Session, February 24th

Propulsion

Reported by J. J. Eden

In Mr. F. H. Keast's absence, Mr. R. H. Guthrie introduced the first speaker, Mr. A. M. Rothrock of the NASA, who spoke on the subject of "Aircraft and Spacecraft Propulsion". The speaker presented a concise and well illustrated review of the fringes of practical knowledge in the propulsion field.

Propulsion Session: (l to r) Mr. A. M. Rothrock, Mr. R. H. Guthrie (Chairman), and Dr. D. C. MacPhail

The various facets of the general propulsion problem of converting an energy source to a propulsive force were categorized and systematically reviewed. Energy sources were related to the specific energy produced. The range of available propellants was divided into those thermally accelerated, electrically accelerated and those radiated. The primary powerplant problem was shown still to be resistance to operating temperatures with immediate goals of operating from 2,000°F to 5,000°F being set for chemical or nuclear rockets. The lecturer outlined possible fields of overcoming the material limitations, such as obtained from plasma which is prevented from contacting the wall material by means of an electro-magnetic field.

Definite applications of thermo and electrical systems for space travel were analyzed, particularly as related to a Moon and a Mars expedition.

Mr. Rothrock's paper, when published in full, will provide a very useful and concise review of the present state of the art in the propulsion field.

For the second paper of this session, Mr. Guthrie introduced Dr. D. C. MacPhail, of the National Research Council, who reviewed "Some Tendencies of Aeronautical Propulsion".

In addition to further analyzing today's propulsion programmes, Dr. MacPhail covered some specific aspects which were under study and development by the NRC at the present time.

SPECIALIST SECTION LUNCHEON

The following report on a formal luncheon held on the 24th February, in conjunction with the Special Anniversary Meeting, has been submitted by Mr. J. A. van der Bliek, Secretary of the Astronautics Section:

This well attended luncheon (approximately 140 members and guests) was organized by the Astronautics and Propulsion Sections of the CAI. After the lunch, Dr. H. S. Ribner, Chairman, introduced the members of the Sections' Executives and touched on the purpose and aims of the Sections.

The luncheon speaker, Dr. J. F. Heard of the David Dunlap Observatory, discussed the physical nature of the planets. In an extremely interesting manner he reviewed data depending primarily on the size and distance from the sun of various planets, such as density, temperature, composition etc, and discussed the possible course of evolution fitting the observations.

Mr. J. J. Eden thanked the speaker for such a fine description of the places to which the propulsion people will be called on to propel their astronautical friends.

The Head Table at the Astronautics and Propulsion Sections' Luncheon: (l to r) Mr. W. F. Campbell, Mr. J. A. van der Bliek, Mr. D. Bogdanoff (all of the Astronautics Section), Dr. H. S. Ribner (Chairman), Dr. J. F. Heard (Principal Speaker), and Mr. E. L. Smith and Mr. J. J. Eden (both of the Propulsion Section)

BRANCHES

NEWS

Vancouver

Reported by G. W. T. Roper

February Meeting

The meeting was held on the 10th February in the Officers' Mess, RCAF Stn. Sea Island. Thirty members and thirteen guests were in attendance.

After a discussion of some Branch business, the Chairman, Mr. R. J. McWilliams, said that the program of the evening would be a panel discussion on "High Pressure Hydraulics", conducted by a panel of experts under the direction of Moderator L. C. Bryan. After additional timely remarks, the Chairman introduced Mr. Bryan who, in turn, introduced the members of the panel who would represent the aircraft manufacturer, the operator and the overhaul agency. In the order listed, these positions were filled by C. Butt, P. W. March and A. McEwan. Each member of the panel, in turn, gave a five minute outline of his experience in his particular field and some of the problems that are encountered. At this point, a debate rolled into action with a lively cross-fire of questions by the panel. In the panel discussion, the manufacturer outlined the increased need for high pressure hydraulics in the faster and larger aircraft which forced the operator to accept high pressure hydraulics, even at increased costs. The overhaul agency elaborated on their plans of maintaining units of this system and, while some additional costs were involved in suitable equipment to test under high pressures, difficulty in maintaining close tolerances has not been experienced. Many questions followed pertaining to manufacture versus operation and overhaul, too numerous to list. However, the panel concluded after some thirty minutes and the meeting broke for intermission.

Following intermission, members were invited to question the panel on problems they were confronted with in the area of high pressure hydraulics. This phase of the debate proved exceptionally lively as many members took part and presented some interesting problems and questions which continued to a later hour than expected. However, it was most interesting and the time expended was well worthwhile.

The panel and members of the audience were thanked by Mr. McWilliams for their fine presentation and participation.

After making a few announcements about the future program, the Chairman adjourned the meeting at 10.45 pm.

Winnipeg

Reported by G. G. Trice

February Meeting

The meeting took place on the 24th February at the Winnipeg Flying Club, following the celebration the previous evening of the 50th Anniversary of Flight in Canada at a special dinner in the Fort Garry Hotel.

An excellent supper was served to 35 members and 22 guests before the meeting. The Chairman, Mr. E. L. Bunnell, introduced the guest speaker, Mr. J. W. Ames, Chief of Equipment and Design Arrow Project, Avro Aircraft Ltd. He said that it was rather unfortunate that Mr. Ames' subject was the development of the ill-fated Arrow, but that he hoped it still held considerable technical interest and requested that members confine their questions to the technical aspects of the subject.

Mr. Ames then presented a very interesting lecture, paying tribute to Mr. Floyd's paper to the R.Ae.S. from which he had borrowed liberally. The speaker illustrated his lecture with many interesting slides showing the construction of the Arrow and its systems and the development rigs used for the very complicated testing required. Some of the highlights of his lecture were his explanations of the flying control system, fuel system and air conditioning system, in which he had taken an active part in the design.

The lecture was completed with the showing of a movie produced by Avro Aircraft Ltd. called "Supersonic Sentinel", which further illustrated the many points which Mr. Ames had brought out during his lecture.

Questions were posed, mainly dealing with range capabilities related to the fuel capacity of the Arrow. Mr. Ames answered them with the general vein that this was the first of a new line of aircraft with much room for development. Space for more fuel tankage was available and would have been developed had the project not been cancelled.

Mr. Kilpatrick thanked Mr. Ames on behalf of the members and guests for his very interesting lecture. The meeting then dissolved into an informal discussion in the lounge of the Flying Club.

Cold Lake

Reported by WO2 J. W. Day

February Meeting

A meeting was held on the 12th February, attended by 11 members. F/L L. S. Lumsdaine introduced the speaker for the evening, Mr. A. L. Sutton, whose subject was "The Iroquois — Canada's Supersonic Turbojet".

Mr. Sutton gave a very interesting talk on the design and manufacture of the Iroquois turbojet engine.

Using experience gained on the production of over 3,780 Orenda engines, the engineering staff of Orenda, in just 20 days, came up with a design for an engine of 20,000 lb thrust, weighing approximately 5,000 lb. This design was presented to and approved by the Hawker Siddeley Design Council and the company spent $8 million as a private venture on the engineering and construction of the Iroquois prototypes.

Using graphs, Mr. Sutton clearly showed how the compressor design was finalized and with the aid of slides the various components and construction methods were depicted. The design of the afterburner, which is fully modulated and an integral part of the engine, was initially sub-contracted. However, due to the many difficulties encountered, a subsequent design by Orenda personnel was adopted and has proven to be much better than anticipated.

Some of the advantages and the problems of manufacture of the latest types of materials, particularly titanium, as used on the Iroquois were explained.

Mr. Sutton then went on to explain the test programs necessary for a newly designed engine the size of the Iroquois. This testing is broken down into several phases and necessitated design and construction of new equipment to test the various components, design and construction of new test cells for engine static testing, and extensive modifications to a USAF B-47 for flight testing. The test program is coming along very well and it is hoped that the first flight in the CF-105 will take place at an early date.

With the showing of the film, "Supersonic Sentinel", Mr. Sutton concluded his address but was asked many questions by his interested listeners at an informal discussion period around the refreshment table. The speaker was thanked by Mr. J. B. Panton.

Calgary

Reported by H. E. Hampshire

March Meeting

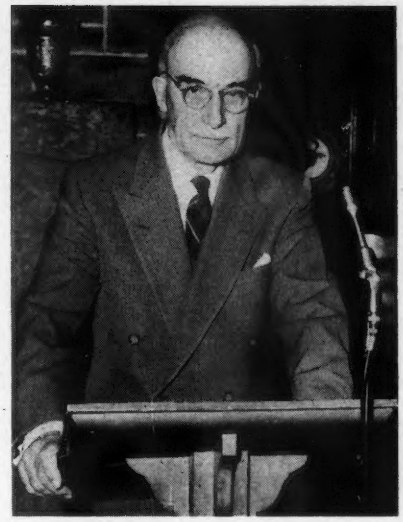
A dinner meeting was held on Tuesday, 3rd March, at the Al-San Club in downtown Calgary. Twenty-two members and guests were in attendance, a fair gathering considering the number of local CAI members who participate in curling activities on a Tuesday evening and, therefore, were unable to be with us.

The meeting was called to order by the Chairman, Mr. W. A. B. Saunders, who then introduced the members and guests at the head table. Following a brief business discussion, the Chairman called upon Mr. N. Armstrong to introduce the guest speaker of the evening, Mr. R. J. McWilliams of Canadian Pacific Airlines Ltd.

Mr. McWilliams, Planning Superintendent at Vancouver, chose for his talk the fascinating subject of some airline applications of "Operations Research". After briefly defining operations research as the scientific study and analysis of management problems affecting the whole company's overall operations, Mr. McWilliams proceeded to enlarge on the "mechanics of management", a new occupation, that of Industrial Engineering. He explained how this particular type of engineering has been applied extensively in the airline production field due to the fact that approximately ⅓ of airline operation costs is spent in the maintenance of aircraft.

Mr. McWilliams then spoke of the broad approach to airline Production Planning and Control, and gave definitions of the basic plans involved, namely, operation plan, technical plan and the integration of the two to produce a production plan. The role of electronic data processing machines and their use as an essential part of operations research was next discussed. Although the cost of purchase or rental of such machines was quite staggering, the time saving element when essential information data is fed into them is most rewarding. In conclusion, Mr. McWilliams gave his views on the future relationship between senior management and the industrial engineer engaged in operations research techniques. A lively question period followed the speaker's talk.

On behalf of the Branch, Mr. W. E. Jamison thanked Mr. McWilliams for his most interesting and informative address.



Mr. J. H. Parkin

Ottawa

Reported by R. L. Wardlaw

March Meeting

The Fiftieth Anniversary of Flight in Canada was celebrated at the Branch meeting on the 11th March, and was held in the RCAF Officers' Mess, Ottawa. On this special occasion the members' ladies were treated to a reception and an excellent buffet supper served in the Mess.

The Branch Chairman, Mr. H. H. Kelland, presided over the meeting that followed. Mr. H. C. Luttman, Secretary CAI, was asked to outline the special activities of the Institute in connection with this Anniversary year. Following this, A/V/M J. A. Easton introduced the guest speaker for the evening, Mr. J. H. Parkin, Hon. F.C.A.I., who is now Senior Consultant, Division of Mechanical Engineering, National Research Council.

Mr. Parkin spoke on "Historical Sidelights of the Aerial Experiment Association". Mr. Parkin has taken a keen, active interest in seeking out the detailed histories of the Association, as such, and of the five associates. Consequently he was able to present a fresh and entertaining account of the sort of people these were that did so much to promote aviation in Canada.

Dr. Bell, McCurdy, Lt. Selfridge, Baldwin and Curtiss were discussed in turn. Their backgrounds before the founding of the Association and the parts they played during the successes of the group were outlined. Mr. Parkin succeeded in doing more than give an historical account — he was able to give some insight into the character of these men and a better appreciation of their accomplishments.

Mr. F. R. Thurston thanked the speaker for his talk, which was not only interesting but also appropriate to the commemoration of the first aircraft flight in Canada.

150 members and guests came out to enjoy the evening's activities.

Some scenes of the Ottawa Branch Meeting

Edmonton

Reported by C. C. Young

February Meeting

The sixth meeting of the Edmonton Branch was held at the RCAF Association, 700 Wing Mess, at 8.00 pm on the 11th February. Mr. C. C. Young, Chairman, presided.

The Chairman welcomed 21 members and 10 guests to the meeting and after the minutes of the fifth meeting had been read by the Secretary, it was proposed by Mr. J. West and seconded by Mr. W. VanHorne that they be adopted as read.

There was no outstanding business to discuss and the Chairman called upon Mr. VanHorne to introduce the guest speaker, Mr. A. L. Sutton, Service Manager, Orenda Engines Ltd.

Mr. Sutton's lecture was entitled "The Iroquois — Canada's Supersonic Turbojet", and he commenced by outlining the background development which had led to the decision to design and build the Iroquois, following this summary with a concise description of the factors governing the design of the components of the engine, the experimental test procedures involved, the selection of materials and fabrication processes, and finally the assembly and testing of the engine.

After a question period, Mr. Sutton showed the Avro colour film "First Flight of the Arrow", which was much appreciated by the audience.

Mr. Sutton was thanked by Mr. A. J. Quick for his able presentation and the meeting was adjourned.

March Meeting

The seventh meeting of the Edmonton Branch was held at the RCAF Association, 700 Wing Mess, at 8.00 pm on the 2nd March.

Mr. C. C. Young, Chairman, welcomed 14 members and 5 guests to the meeting.

The Secretary read the minutes of the sixth meeting and it was proposed by Mr. C. W. Arnold and seconded by Mr. J. G. Portlock that they be adopted as read.

There being no business to discuss, the Chairman called on Mr. Portlock to introduce the guest speaker, Mr. R. J. McWilliams, Superintendent of Planning, Canadian Pacific Airlines, whose subject was "Airlines Operation Research".

Mr. McWilliams said that he hoped to show that the problems of airline operation, since many of them are essentially quantitative, can submit to the analytical methods of the physical sciences. It is sincerely believed that in many areas operations can be represented by, and therefore optimized more efficiently through, the use of mathematical models or the process of system simulation using the computer. Further, it is hoped to show that the services of a properly trained research team, using new operations research tools for problem solving, will repay senior management by providing reliable information for sound predictions and decisions.

The speaker was thanked by Mr. C. C. Young.

Halifax-Dartmouth

Reported by Lt. J. A. Turner

February Meeting

In cooperation with the Association of Nova Scotia Professional Engineers, the Halifax Branch of the Engineering Institute of Canada and the Halifax-Dartmouth Branch of the Canadian Aeronautical Institute, a reception and banquet was held at the Nova Scotia Hotel, Halifax, on the 23rd February, to commemorate the Fiftieth Anniversary of Flight in Canada.

Prior to the banquet those attending had an opportunity to view an attractive display of aircraft models which had been made available by the Fairey Aviation Co. In addition to the models, the Committee had arranged for some original photographs of early developments in the aviation field to be on view.

The Chairman, CPO R. L. S. Sabourin, introduced the Head Table to the 225 guests in attendance. Special dignitaries included the Hon. R. L. Stanfield, Premier of Nova Scotia, Rear-Admiral H. F. Pullen, Major-General M. P. Bogert and Air Commodore W. L. Clements.

Mr. J. D. Kline, President of the A.P.E. of Nova Scotia, introduced the speaker for the evening, Mr. D. O. Turnbull. Mr. Turnbull is the son of the late Dr. W. R. Turnbull, who was one of the early pioneers in aeronautical research.

Mr. Turnbull spoke of his father's early work in aviation, from the time when he graduated from Cornell University in 1889 until his retirement from active work in 1948.

After working for 4 years with the Edison Lamp Co. in the U.S.A., Dr. Turnbull returned to his home in New Brunswick and established his aeronautical research laboratory in a barn. From the beginning of his experiments, he realized that a constant source of uniform airflow was essential if his results were to be comparable. He, therefore, designed and built the first wind tunnel in Canada, in 1902.

With the aid of the wind tunnel, he conducted research in aerofoil design in order to investigate the problem of the lack of longitudinal stability—"the same problem which caused the replica of the Silver Dart to crash at Baddeck". Dr. Turnbull discovered and later formulated laws governing stability.

He next turned to the overall efficiency of aircraft and came up with the idea, novel at that time, that the air screw was not the most efficient means of driving an aeroplane. From 1909 until 1937, Dr. Turnbull worked on propeller research, both in Canada and in England. During this time he concentrated his efforts on developing a variable pitch propeller and subsequently produced the first successful controllable pitch propeller to be tested in the world.

Dr. Turnbull was not known as well in his native country for his achievements in the field of aerodynamics as he was in other countries, as most of his important work and inventions were used in the United States and England.

In his conclusion, the speaker noted that "the air age is young, vigorous and growing, and that within the next ten years the progress will make the first 50 years look like the plodding of an ox".

The speaker was thanked by Mr. W. J. Phillips, President of the Halifax Branch of the E.I.C.

MEMBERS

NEWS

Hon. J. A. D. McCurdy, Hon. F.C.A.I., has been appointed Honorary Air Commodore of the RCAF.

R. F. Hunt, A.F.C.A.I., President of Dowty Equipment of Canada Ltd., has been appointed Deputy Chairman of Dowty Group Ltd. with headquarters in Cheltenham, England.

W/C H. Pearce, A.F.C.A.I., has relinquished his appointment as Coordinator for the National Coordinating Council for the Golden Anniversary of Flight in Canada to take up a position with the Standard Motor Co., Toronto.

L. G. Brooks, M.C.A.I., formerly with Orenda Engines Ltd., is now engaged with Kirk Equipment Ltd. as Technical Sales Representative.

L. L. Jones, M.C.A.I., has been appointed Manager of Toronto and District Sales Operations of Aviation Electric Ltd.

A. T. Smith, M.C.A.I., has left Avro Aircraft Ltd. to take up a position as Dynamicist with Stanley Aviation Corp., Denver, Colo.

A. W. Stewart, M.C.A.I., has been appointed Plant Manager of the Toronto facility of Carriere and MacFeeters Ltd.

L. W. Wilkins, M.C.A.I., recently with Dowty Equipment of Canada Ltd., has moved to San Diego to join Convair.

A. J. Comeau, Technical Member, has left Garrett Manufacturing Corp. and is now in a new position with the Dept. of National Defence at the Central Experimental and Proving Establishment, Uplands.

V. Pullishy, Technical Member, has left Canadair to take up a position in the Pilotless Aircraft Div., Boeing Airplane Co., Seattle.

F. E. Roy, Student, formerly an Engineer-in-Training at Avro Aircraft Ltd., has accepted a position with the Dept. of National Defence, Inspection Services, in Ottawa.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 26th February, 1959, the following were admitted to the grades shown.

Member

D. R. B. Anderson, Assistant Chief Test Pilot, Canadian Pacific Air Lines (Repairs) Ltd., Calgary, Alta.: *1917 Glenwood Dr., Calgary, Alta.*

C. F. Baldwin, Chief of Flight Operations, Safe Flight Instrument Corp., 4 Water St., White Plains, N.Y.

S. Emer (on transfer from Technical Member)

P. W. S. James (on regrading from Technical Member)

J. D. Lovatt (on transfer from Technical Member)

R. A. J. Murison (on transfer from Associate)

W. M. Staines (on transfer from Technical Member)

K. A. Wilkes (on transfer from Technical Member)

Technical Member

Lt. (E) (AE) W. H. Atwood, RCN, Engineering Dept., RCN Air Station, Shearwater, N.S.: *21 Glenwood Ave., Dartmouth, N.S.*

R. M. Barnes (on transfer from Junior Member)

B. S. Bell, Mechanic, Trans-Canada Air Lines, Winnipeg, Man.: *2031 Gallagher Ave., Winnipeg, Man.*

C. A. Bond, Senior Planner, Aircraft Assembly, Avro Aircraft Ltd., Malton, Ont.: *1142 Tisdale St., Oakville, Ont.*

CPO L. Choquette, RCN, Engineer Officer, Naval Air Establishment VU33, Patricia Bay Airport, B.C.: *580 Forward Dr., Belmont Park, Victoria, B.C.*

F/O D. J. Gilpin (on transfer from Student)

F/O S. G. Morin (on transfer from Student)

F/O D. W. Tufts (on transfer from Student)

Junior Member

F. R. Ohnstad (on transfer from Student)

Student

R. R. Baker, Ryerson Institute of Technology, Toronto, Ont.: *351 Fairlawn Ave., Toronto 12, Ont.*

J. D. Bannister, University of Toronto, Toronto, Ont.: *28 Ashton Manor, Toronto 18, Ont.*

Cadet J. C. Bauer, Canadian Services College, Royal Roads, Victoria, B.C.

Associate

G. W. Band, Secretary-Treasurer, Bristol Aero-Industries Ltd. (Winnipeg Division), Box 874, Winnipeg, Man.

At a meeting of the Admissions Committee, held on the 5th March, 1959, the following were admitted to the grades shown.

Associate Fellow

A. C. Earle, Plant Manager, The Fairey Aviation Co. of Canada Ltd., Dartmouth, N.S.: *23 Glenwood Ave., Dartmouth, N.S.*

M. A. Phipps, Chief Design Services Engineer, Orenda Engines Ltd., Malton, Ont.: *9 Waterton Rd., Toronto 15, Ont.*

E. Wall, Chief Engineer, Guided Missile Div., De Havilland Aircraft of Canada Ltd., Downsview, Ont.

Member

O. Cleven, Section Head, Canadair Ltd., Montreal, P.Q.: *339 Marlatt St., Ville St. Laurent, P.Q.*

L. B. Clifford, Senior Engineer, Canadair Ltd., Montreal, P.Q.: *97 Chester Ave., Valois, P.Q.*

W. E. Cunningham, Electronic Project Engineer, Northwest Industries Ltd., Edmonton, Alta.: *10265 Princess Elizabeth Ave., Edmonton, Alta.*

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The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

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Trainees: From time to time we have openings for young men 17 to 25 interested in careers in aviation to participate in our trainee programme. Applicants should have eleventh grade education, although this is not essential, and must be mechanically inclined. Trainees are employed in our shops while taking international correspondence schools course at home. Good pay — cost of course by payroll deduction with rebate upon successful completion. As courses are in English, applicants must be English speaking or completely bilingual. Apply in writing to: Personnel Manager, Aircraft Industries of Canada Ltd., P.O. Box 100, St. Johns, P.Q.

SUSTAINING MEMBERS

NEWS

Avro Aircraft Ltd. and Orenda Engines Ltd. have issued no formal statement known to the Institute regarding their present activities. However it can be reported that on the 20th February the Prime Minister announced the Government's decision to terminate the contracts for the Arrow and the Iroquois engine to be installed in it. The reason for the cancellation was given in a broadcast speech delivered by the Prime Minister on the 9th March as follows:

"There was ample evidence before the Cabinet that the Arrow would be obsolete before it could be delivered even in minimum quantity in 1961. The advice of the Chiefs of Staff was that this aircraft would be obsolete, having regard to the new danger of attack by missile rather than by manned aircraft. The Arrow would not be effective against missile attack but we were advised that Canada's CF-100 and comparable United States' Aircraft Squadrons could meet any manned bomber attack likely to be delivered."

To meet the threat from ICBM, the Government had decided to establish two Bomarc squadrons.

When the announcement was first made on the 20th February, both Companies immediately dismissed all their employees, amounting to over 13,000 people. Since then steps have been taken to rehire some 2,500 of them and the possibilities of entering into contracts for the loan of engineering personnel to American companies (as recently done by Canadair Ltd. to the Boeing Airplane Company) have been explored.

BOOKS

Nuclear Propulsion and Engineering for Engineers. BY D. G. SAMARAS. Technical Chamber of Greece, Athens, 1958. 701 pages. Illus. $18 to libraries, $12 to scientists, plus 50c postage.

This sizeable volume has been designed by the author to furnish scientists and engineers interested in the practical application of nuclear energy with a simplified body of fundamental nuclear physics and an up-to-date and far ranging collection of data pertaining to nuclear engineering in general, with particular reference and emphasis on nuclear propulsion in aviation. The author is a professor of nuclear propulsion at Ohio State University Graduate Centre.

Chapters are devoted to a general discussion of sources of energy for propulsion, nuclear reactions as energy source, the role of neutrons in nuclear energy release, an account of associated radio activity, the steady and unsteady operation and control of various reactor types, a detailed discussion of properties of construction materials for propulsion reactors, aircraft shielding requirements and design, the extraction of nuclear energy as heat and in electrical form and its transformation indirectly and directly into electrical energy, utilization of nuclear energy in turbojets, ramjets, rockets etc and, finally, a summing up of future prospects. The text is liberally illustrated by several hundred figures, mostly in the form of graphs, and reinforced by about a hundred tables involving a considerable weight of collected data of value to reactor engineers.

R. A. TYLER

Dynamics of Flight — Stability and Control. By B. ETKIN. John Wiley & Sons, Inc., New York, 1959. 519 pages. Illus. $15.00.

Professor Etkin of the University of Toronto is well known to the readers of this Journal and to the Canadian aeronautical engineering community at large. He has been singularly successful in combining his teaching and engineering experiences to write a textbook which will have a wide appeal, from students to practising engineers, and it seems that there was no need for the publisher to advertise this work as belonging to "space technology" – a current, but inaccurate, trend. Professor Etkin's style is lucid and concise, the subject matter well organized and the book well produced.

In some 500 pages, the standard aspects of aircraft stability and control are covered using essentially the NACA derivative notation. The application of theory is often demonstrated by engineering-type numerical examples. In addition, a number of important topics, not found in older works, are included in Chapters 9 to 14. Here belong Airplane Response Calculations, Flight in Turbulent Air, Automatic Stability and Control, Machine Computation and Simulation. This more advanced material is preceded by Chapter 8, on Some Mathematical Aids, which deals with the Laplace transform and other mathematical techniques important in airplane dynamics. Four appendices on Vector Analysis, Aerodynamic Data (based essentially on R.Ae.S. Data Sheets and NACA Reports), Standard Atmosphere and definitions of Mean Aerodynamic Chord and Center complete the book. Each chapter contains an up-to-date and significant bibliography.

Chapters 11 and 13 on Inverse Problems and on Specialization to Missiles are of particular interest to the Canadian reader, in that they often refer to Canadian work.

In Chapter 11 are summarized some of Professor Etkin's contributions on applications of the inverse techniques to performance and load calculations. Chapter 13 contains many illustrations obtained from missile studies in the CARDE Aeroballistic Range at Valcartier, Que.

In conclusion, Dynamics of Flight can be highly recommended to all interested in this important aspect of aeronautical engineering.

J. LUKASIEWICZ

Aircraft Engines of the World, 1958/59. BY P. H. WILKINSON, Washington, D.C., 1959. 320 pages. Illus. $15.00.

This book contains a wealth of fundamental information concerning a complete list of aircraft engines employed and under development throughout the countries of the western and eastern world. One or two pages are devoted to each engine, showing an illustration and comprehensively stating performance figures, installation data, general construction and material features, component and accessory details, and the various models derived from the basic design. Although the information is adequate for a preliminary assessment against a given powerplant requirement, the real value of the book lies in the availability of those evasive technical details so often desired.

An introductory section on nuclear powerplants, summarizing the objectives and progress of the open and closed cycle developments, is considered of timely interest. Ramjets and rocketjets occupy the first few pages signifying, no doubt, the important role of these powerplants as the missile era beckons. The inventory of specialized gas turbines illustrates the different configurations recently emerging as aircraft turbo-compressors and turboshaft power units. The trend towards production of small, high performance turbojets and turboprops, in marked contrast to the position of exclusiveness occupied by very large engines, is evident on reviewing the gas turbine group. The familiar reciprocating engines, persistently maintaining a place of significance in aviation, have not been neglected. Fuels and lubricants are also tabulated, including corresponding specifications of several countries. The space provided for cataloguing the engines used in military and civil aircraft of the world will conveniently answer the ever topical questions on applications of engines.

To conclude, the material held within the covers of this book will challenge, in general usefulness, the best organized accumulation of engine literature available to the operator or engineer.

S/L W. R. Cole

Letter to the Editor

The book "The Silver Dart" by H. Gordon Green, published under the authority of the National Coordinating Council for the Golden Anniversary of Flight in Canada, is described on the cover as "The Authentic Story of the Hon. J. A. D. McCurdy, Canada's First Pilot".

Thus described and sponsored, the book may reasonably be expected to be accurate as to facts. Indeed, since there are lengthy verbatim extracts from the Bulletins of the Aerial Experiment Association, the author evidently had access to the Bulletins which record in detail the actual operations and achievements of the Association.

Readers entertaining any such expectations will be disappointed. There are inaccuracies as to fact in the book.

No one who knows J. A. D. McCurdy will for a moment believe that the mis-statements originated with him. Unfortunately those at home and abroad who do not know him may reasonably ascribe the inaccurate claims made in the book to Mr. McCurdy, which is regrettable.

Biographies are normally factual rather than imaginative and care is taken by authors that their facts are accurate. With the detailed technical story apparently available to him, inaccuracies such as the following are inexcusable.

p 41 – "It was inevitable now that the inventors should think of putting one of Curtiss's efficient little motorcycle engines into a glider. The result was . . . the Red Wing."

The Red Wing was designed from the start as a powered aircraft and in no sense improvised from a glider.

p 45 – "The motor which had lifted the Red Wing had passed into oblivion with the plane itself . . ."

The same motor was used successively to power the Red Wing, White Wing and June Bug.

p 56 – "In October . . . dismantled the Loon and put her into crates. The completed parts of the latest plane were also crated for shipment."

It is implied that both the Loon and Silver Dart entered Canada. It is doubtful if the Loon ever left Hammondsport. It certainly never entered Canada.

p 56 – "The result was the world's first water-cooled aircraft engine, with copper-jacketed cylinders."

The Antoinette engine of 1905-07 was fitted with electrolytically deposited copper water jackets.

p 107 – Respecting the flights of the Silver Dart at Petawawa on 2 August, 1909, there are references to the Dart being paraded before officers, to a fifth flight, to turns, and to flights of about a mile in length.

Inasmuch as the flights started at 4.00 am and the last flight was made as the sun came up over the horizon, there was no parade before officers. Only four flights were made, all more or less in a straight line, and for a distance of about ½ of a mile.

p 108 – "Baldwin had witnessed the proceedings from the ground and . . ."

Baldwin was a passenger with McCurdy on the second and fourth flights. The second flight was the first passenger flight made in Canada.

p 155 – "He had not only been the first Britisher to make a controlled flight . . . he had contributed largely to the invention of the aileron, the tricycle landing gear . . . he had been the first man to fly a plane powered by a water-cooled motor . . ."

Baldwin was born in Toronto, Canada, and was at the controls and presumably used them when a strut failed on his flight in the Red Wing on 12 March, 1908. Incidentally, Baldwin was thus "Canada's First Pilot".

The aileron was suggested by Dr. Bell in a letter to Baldwin, and Baldwin implemented the suggestion in his White Wing.

The Phillips machine of 1904, Ellakammer machine of 1905 and Santos-Dumont machine of 1906 all had tricycle undercarriages.

The Wright brothers, Santos-Dumont, Bleriot and Farman all flew with water-cooled engines before 6 December, 1908.

p 157 – "In 1928 he formed the Reid Aircraft Company and established a plant in Montreal . . ."

The Reid Aircraft Company Limited was formed by Mr. W. T. Reid to build the Rambler, which he had designed, and the Board of Directors did not include Mr. McCurdy.

p 193 – "He was chief engineer of the Aerial Experiment Association from 1906 to 1909 . . ."

The Aerial Experiment Association came into being on 1 October, 1907.

p 197 – "First Aeroplane Flights; December 17, 1903 – Orville Wright . . .; October 23, 1906 – Alberto Santos-Dumont . . ."

Wilbur Wright also flew before Santos-Dumont.

Inaccuracies, such as the foregoing, cast doubt on other statements in the book which are less readily checked.

The author has done a disservice to Mr. McCurdy, Canadian aviation and the Coordinating Council in making such extravagant claims. It is a pity because Mr. McCurdy has so many claims to fame that exaggeration is unnecessary.

Ottawa — J. H. Parkin

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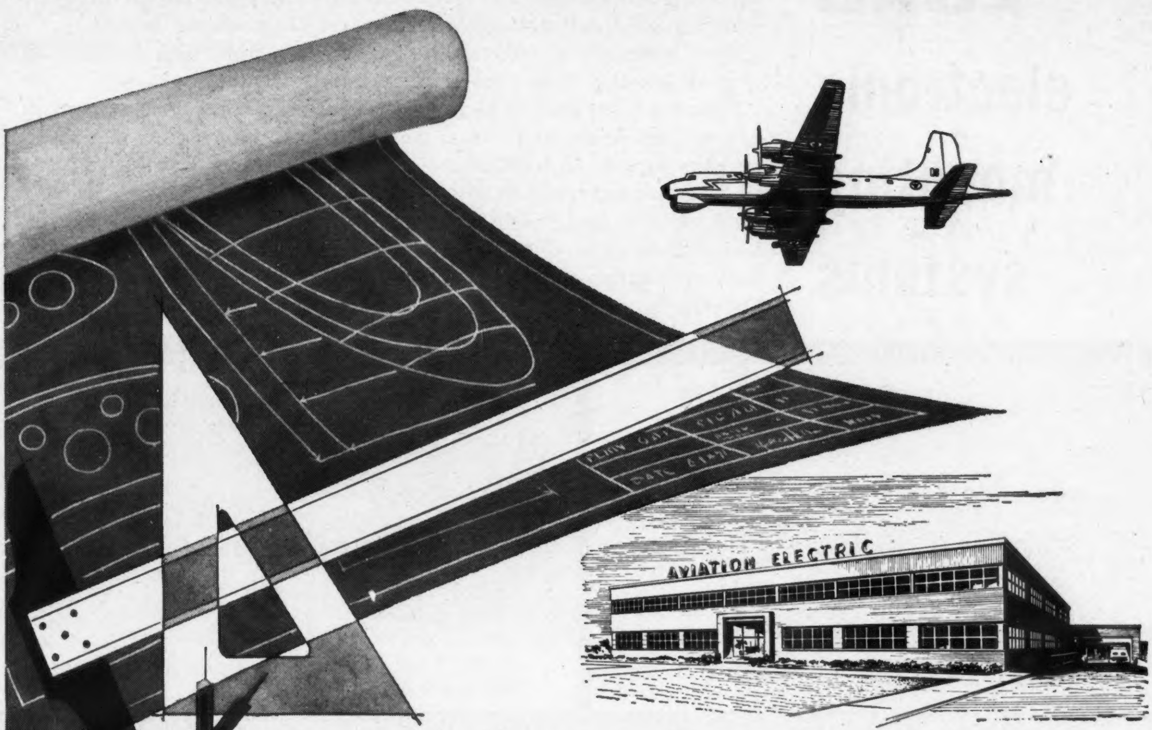

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